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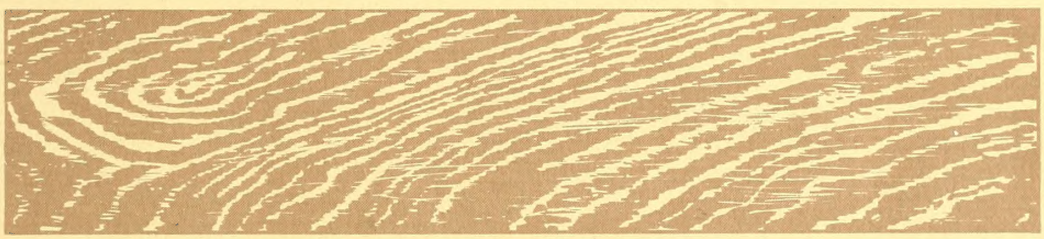
HARDWOOD SIDING PERFORMANCE



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HARDWOOD SIDING PERFORMANCE

By

GLENN A. COOPER

Introduction

After 6 years of tests on a noninsulated storage building, yellow-poplar siding had performed better than siding made from five other hardwood species. Tongue-and-groove siding outperformed board-and-batten siding or horizontal clapboard, and siding treated with a water repellent and pentachlorophenol was superior to siding treated with penta alone. Red oak was a close second to yellow-poplar in performance and cost slightly less to install. Beech gave the poorest service; and soft maple cost the least per square foot. Generally, for all species tested, the most severe types of failure were opening of vertical joints between boards and splitting of the siding boards and battens.

Before 1875, hardwoods were the chief construction woods in the Midwest. When softwood lumber became readily available, the use of hardwoods diminished. Today relatively small amounts of hardwoods are used for construction, even where supplies are plentiful.

The declining use of hardwoods was due mainly to difficulties in nailing, seasoning, and painting them compared to softwoods. However, portable pneumatic nailers, improved seasoning techniques, and new finishes have eliminated some of these difficulties. Although hardwoods are not likely to replace large volumes of softwoods for construction, they can be used to a greater extent than at present. They must, however, be used properly or they will not perform well.

NOTE: *The author is Associate Forest Products Technologist, North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, St. Paul, Minn. He is headquartered at the Station's field office in Carbondale, Ill., which is maintained in cooperation with Southern Illinois University.*

The Test

On the 124-foot-long north and south sides of our test building we installed vertical board-and-batten and tongue-and-groove panels made from yellow-poplar and red oak, and board-and-batten panels made of hickory, beech, sycamore, and soft maple.

For each yellow-poplar and red oak panel, one-third of the boards were dipped 3 minutes in a 5-percent solution of pentachlorophenol in mineral spirits with a water repellent, one-third were dipped 3 minutes in a pentachlorophenol solution without a water repellent, and one-third were installed untreated.

For each beech and hickory panel half of the boards were soaked 3 minutes in the water-repellent penta solution and half were installed untreated. And for the sycamore and soft maple panels, half of the boards were soaked in penta and the remainder were left untreated.

On the 40-foot-wide ends of the building (east and west exposures) we tested panels

of yellow-poplar and red oak horizontal clapboard siding. Half of the boards for each panel were treated with water-repellent penta and half with penta. We installed elm board-and-batten siding in the gables, and tongue-and-grooved cottonwood and ash in 10- by 12-foot sliding doors. Half of the boards were treated with penta and half were untreated (fig. 1, table 1).

Poles on 16- and 12-foot centers supported oak and hickory horizontal girts (ribbands) 3 feet apart on the side walls. Studs on the end walls were on 2-foot centers. Siding was installed from 4 inches above grade to the soffit at 12 feet, 4 inches. There were no gutters, and the roof overhang was 8 inches, so the siding was exposed to sun and rain.

The boards in the board-and-batten siding were from 3½ to 7½ inches wide and ¾ inch thick. Most of the siding boards and battens were full-length (12 feet); but to meet defect limitations[1] and obtain better yields we also used some 3-, 6-, and 9-foot boards and battens butted and staggered on the girts. Boards were spaced ¾ inch apart, and the ¾-inch-thick by 2½-inch-wide battens were centered

[1] *Defect limitations: All siding used was free of decay, loose knots, knot holes and other holes larger than ¼ inch in diameter, splits, shake, exposed pith, and sloped grain in excess of 1 in 10. Allowable defects were pin, shot, and worm holes up to ¼ inch in diameter; burls, stain, streak, seasoning checks, enclosed pith, tight knots up to 1¼ inches in diameter, and tight knot clusters.*

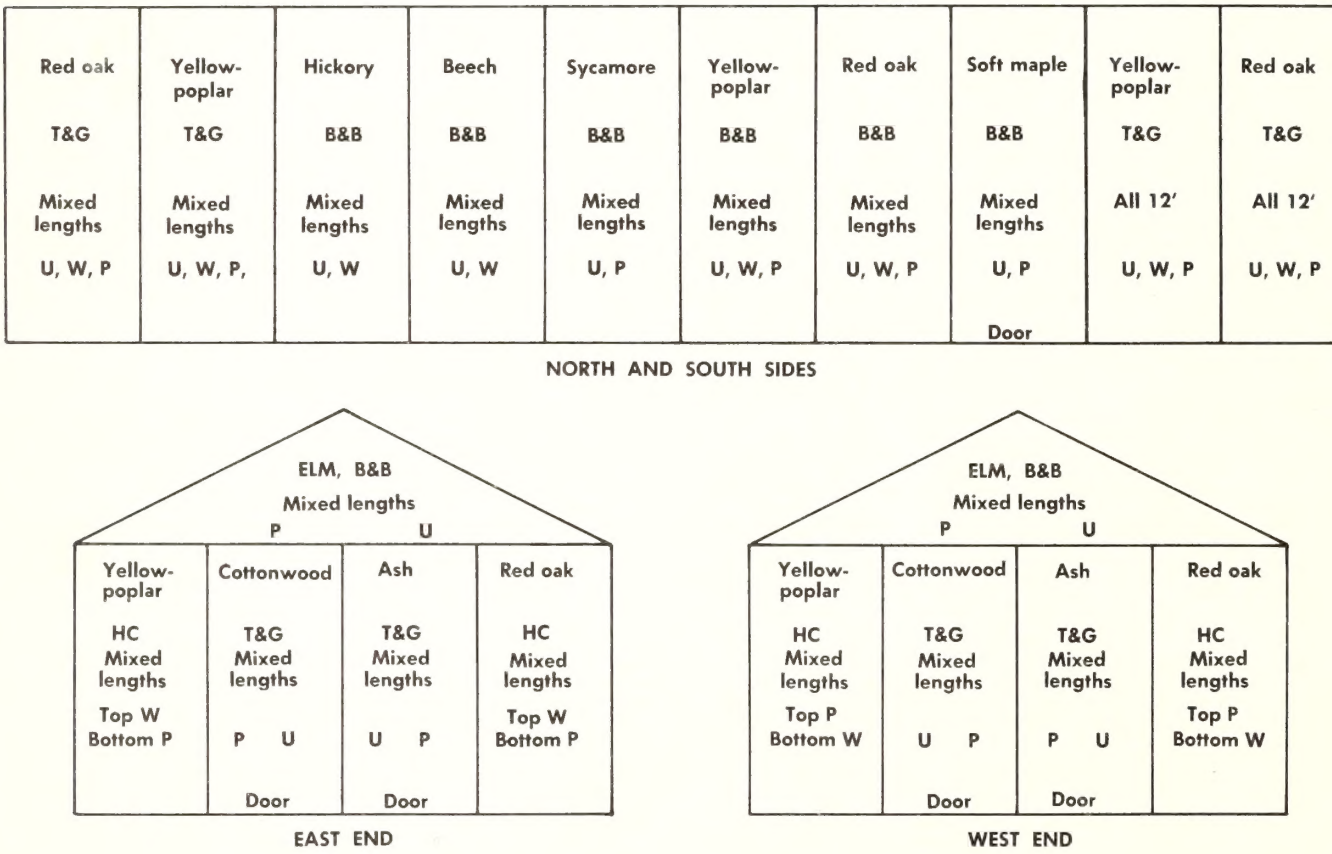

Figure 1.—Species, style, board length, treatment, and location of the test panels. Styles were T&G (tongue-and-groove), B&B (board-and-batten), and HC (horizontal clapboard). Treatments were P (pentachlorophenol), W (water-repellent penta), and U (untreated).

Table 1.—The variables tested

Species	Siding style	Treatment[1/]
ON THE NORTH AND SOUTH SIDE WALLS (PRIMARY TEST)		
Yellow-poplar and red oak	Board-and-batten	Untreated
		Penta
		WR penta
	Tongue-and-groove	Untreated
		Penta
		WR penta
Beech and hickory	Board-and-batten	Untreated
		WR penta
Sycamore and soft maple	Board-and-batten	Untreated
		Penta
ON THE EAST AND WEST END WALLS (SECONDARY TEST)		
Yellow-poplar and red oak	Horizontal clapboard	Penta
		WR penta
Ash and cottonwood	Tongue-and-groove	Untreated
		Penta
American elm	Board-and-batten	Untreated
		Penta

[1/] Penta = pentachlorophenol; WR penta = water-repellent pentachlorophenol.

over the gap. Boards were surfaced on the heart side and installed with the rough bark side to the weather. The boards were nailed to each girt with two 8-penny, 2½-inch, galvanized, threaded nails; and battens were fastened to each girt with one 10-penny, 3-inch, galvanized, threaded nail.[2] Board nails were 1¾ to 5 inches apart within each girt.

Tongue-and-groove siding was ¾ inch thick and 3⅝, 5⅝, or 7⅝ inches wide. Both sides were surfaced. Tongues were ⅜ inch wide by ⅛ inch thick, and grooves were 7/16 inch deep. Two panels each of oak and yellow-poplar were made from 12-foot boards. The other panels were of mixed-length boards (3-, 6-, 9-, and 12-foot). Butt joints were staggered, and the bark side was faced to the weather. The 3⅝-inch and 5⅝-inch boards had two nails at each girt, and the 7⅝-inch boards had three nails. Spacing between outside nails varied from 1¾ to 5 inches.

Horizontal clapboard siding was 13/16 inch thick, 7½ inches wide, and 4, 8, or 10 feet long. It was surfaced one side and installed with the rough face to the weather with a 1-inch overlap. Boards were nailed to each stud with one 8-penny 2½-inch galvanized threaded nail about 1¼ inches above the bottom edge of the board.

All siding studs and girts had about a 16-percent moisture content when installed. This is approximately the mean equilibrium moisture content for wood in outdoor use in southern Illinois. During the test, the moisture content of the siding varied from 12 to 20 percent; and at the final inspection, after a dry summer and fall, it averaged 12 percent.

Immediately after installation, the siding was brush-coated with the Forest Products

[2] *All siding nails were furnished through the courtesy of Threaded Nails, Inc., Skokie, Ill. A 0.125-inch drill was used to predrill for both the 8d and 10d nails which were 0.148 inch and 0.153 inch in root diameter, respectively.*

Laboratory natural stain,[3] containing double-strength cedar color pigment.

Method of Evaluating Performance

The initial condition of the siding was recorded after it was installed in October 1960. Subsequent inspections were made each May and October for 6 years, and spot inspections were made after heavy rain and wind storms.

We evaluated siding performance by four criteria: weather-tightness of joints, amount of board splitting, number of popped nails, and amount of checking. Decay, originally considered a principal criterion, occurred so seldom that it was relegated to a group of secondary criteria; these included water staining on the unfinished interior sides of the boards, finish performance, and resistance to woodpecker damage.

Weathertightness was determined by counting the leaky joints, by measuring the lineal inches of no contact (light leaks) between boards or between boards and battens, and by noting the extent of water stain on the inner face of the siding panels.

Splitting frequency was rated by the total length of splits longer than 4 inches divided by the total length of boards and battens.

Checking was subjectively rated from 0 to 100 percent: A siding panel with only a few superficial or short checks was considered 10 percent checked. If a test panel contained checks in every square foot or had many scattered deep, wide, and long checks, it was rated as 90 percent checked. Other ratings were scaled proportionately.

Fastener tightness was rated by the number of popped nails versus the total number of visible nails in a panel (some nails were covered by battens or a frieze board). If the underside of a nail head was not in contact with the board surface, it was considered popped.

All performance characteristics measured by the secondary criteria were recorded by photographs and notes.

Species Differences

On the North and South Sides

Only untreated board-and-batten panels were installed for all six species tested on the north and south walls. Therefore, the following species comparisons refer only to these panels.

Yellow-poplar performed the best (table 2): Less than 3 percent of the total joint length leaked, splits were less frequent, nail pops fewer, and checking less severe than in any of the other species. Furthermore, the yellow-poplar wood was stable, it developed very little warp or raised grain, and it held the finish better than the other species.

Red oak siding ranked a close second to yellow-poplar: Less than 4 percent of the total length of joints leaked. Splits were more frequent in the red oak than in the yellow-poplar, but most splits were less than 6 inches long and were located at the bottom of the panels where the horizontal girt prevented through-the-panel leakage. About 2 percent of the nails were popped, and most of them were in battens. The red oak was all flat sawn and, as might be expected, checked considerably — 50 percent — about the rays. However, all checks were short and shallow.

Hickory was intermediate in performance. Thirteen percent of the total joint length in the panels leaked. These leaks were chiefly due to warping of the battens. Six percent of the hickory siding parts had splits, slightly more of them in the battens than in the boards. Three percent of the nails popped, most of them in battens (fig. 2). Eighty percent of the panel surface area was checked, and the checks were longer and deeper than in red oak.

[3] *U.S. Forest Service, Forest Products Laboratory. Forest Products Laboratory natural finish. Report No. 2096, 9 pp., illus. 1957.*

Table 2.—Percent of failures in untreated board-and-batten siding for six hardwood species, by type of failure

Species	Type of failure			
	Leaks[1/]	Splits[2/]	Nail pops[3/]	Checks[4/]
Yellow-poplar	3	2	2	25
Red oak	4	5	2	50
Hickory	13	6	3	80
Soft maple	13	21	4	60
Sycamore	30	20	6	60
Beech	40	8	7	90

[1/] Length of leaky joints between boards divided by total length of joints between boards x 100.

[2/] Number of splits over 4 inches long divided by total length of boards in panels x 100.

[3/] Number of popped nails divided by total number of exposed nail heads in panels x 100.

[4/] Number of square feet of checked panels divided by total square feet in panels x 100. Exterior side only.

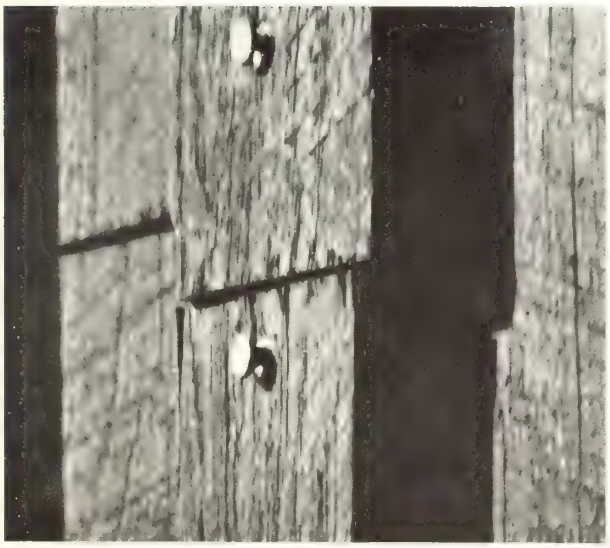

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Figure 2.—Popped nails in hickory battens. Most popped nails were not this far out.

Soft maple siding was also intermediate in performance. About 13 percent of total joint length leaked, chiefly due to warp of both boards and battens. Soft maple split more than the other species tested (21 percent of the boards or battens contained splits), and most of the splits developed at the nails in battens. Four percent of the nails were popped, with about the same frequency in boards as in battens. Sixty percent of the panel surface area had short, shallow checks and occasional long, deep checks.

Sycamore performed noticeably poorer than any species except beech. The untreated sycamore joints leaked along 30 percent of their total length, partly because of considerable warp of the battens. Nail popping (6 percent) and checking (60 percent) were about the same as for soft maple. Splitting (20 percent) occurred mainly as a few long splits (fig. 3).

Beech performed poorest of the six species by all test criteria except splitting where it ranked fourth. Leaks occurred along 40 percent of total joint length and were larger than in the other woods due to greater warpage of the boards and battens (fig. 4). Checks were of moderate size compared to the other species, but 90 percent of the test surface had many closely spaced checks (fig. 5).

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Figure 3.—Sycamore board-and-batten siding, untreated, south wall, with long mid-board splits.

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Figure 4.—This beech batten bowed over ¼ inch away from the adjacent boards.

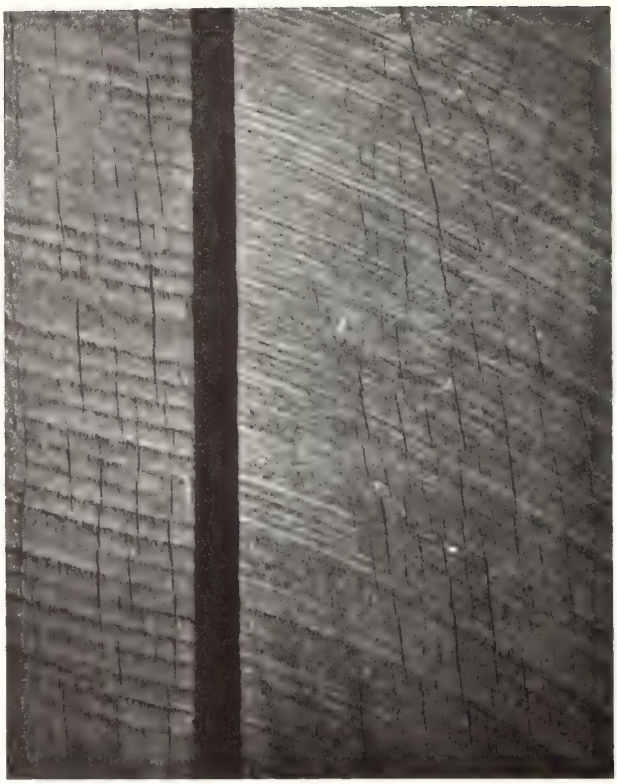

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Figure 5.—Checking in beech board-and-batten siding was extensive but did not reduce the utility of the siding.

On the East and West End Walls

On the east and west end walls the yellow-poplar and red oak horizontal clapboard siding performed better than either the tongue-and-groove ash and cottonwood or the board-and-batten elm in all respects except weathertightness. However, siding style, not species, caused more leaks in the red oak and yellow-poplar.

The cottonwood was inferior to the ash because it warped badly. In two instances tongue-and-groove joints in cottonwood panels became disengaged, causing a leak. Furthermore, the cottonwood had more splits and nail pops than the ash. Longitudinal shrinkage (probably due to concentrations of tension wood) was apparent at the butt joints in the cottonwood but not in the ash (figs. 6 and 7). This longitudinal shrinkage

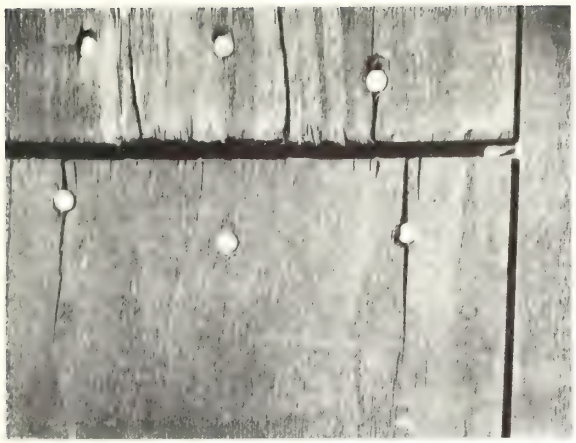

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Figure 6.—This ¼-inch butt joint gap in cottonwood tongue-and-groove siding resulted from excessive longitudinal shrinkage, particularly in the upper board. The indentation of the nail at upper right, and the splitting at nails is further evidence of longitudinal change.

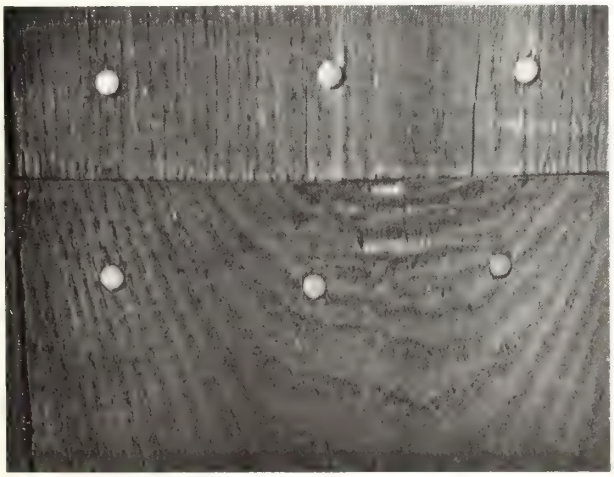

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Figure 7.—Tight butt joints in ash with the same treatment and exposure as the cottonwood in figure 6. Note the absence of end splits at the nails.

caused splits at the nails. The cottonwood also was more cupped than the ash.

Elm board-and-batten siding in the gables was unsatisfactory because most of the battens warped, creating joint leaks.

Style Differences

Siding style comparisons are limited to the red oak and yellow-poplar because the other woods were tested in one style only. Furthermore, to avoid confounding style and treatment effects on performance, style comparisons are limited to the panels treated with penta and water-repellent penta (horizontal clapboard was not tested untreated—table 1).

Differences in the red oak and yellow-poplar siding styles were clearly evident. Tongue-and-groove siding was the most watertight (figs. 8 and 9). Only one leak in the 16 test panels occurred, and this was due to tongue breakage during installation. There was less water staining on the inside of these panels than in the other styles because the

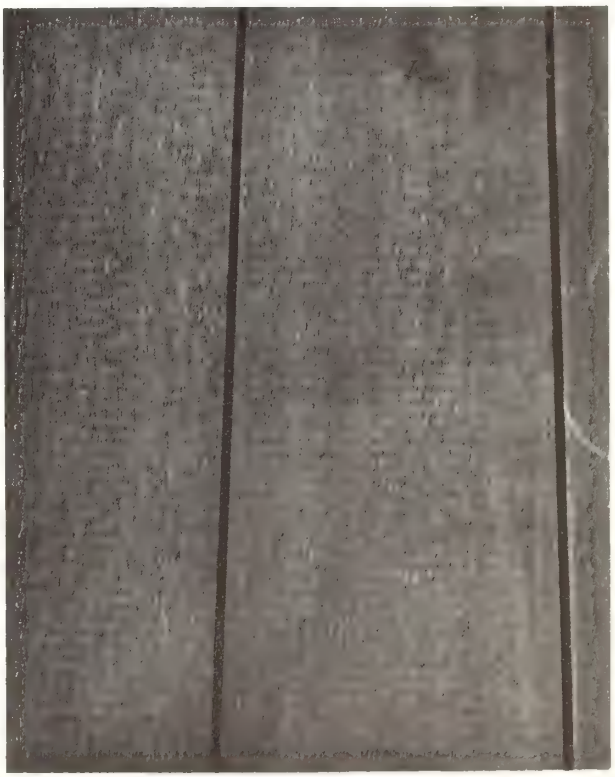

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Figure 8.—Yellow-poplar tongue-and-groove siding, water repellent treatment on the south wall. The boards have shrunk exposing 3/16 inch of tongue, but the joint is tight.

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Figure 9.—Yellow-poplar tongue-and-groove siding, water repellent treatment on the north wall. Shrinkage has exposed less than 1/16 inch of tongue, joints are tight, and checking is almost invisible.

joints remained tight. Furthermore, after rain storms there was no free water on the inside of the tongue - and - groove siding, whereas there was on the other sidings.

Board-and-batten siding did not perform nearly as well as the tongue - and - groove siding. Battens that warped or were loosened by nail pops did not remain flush to the boards (see fig. 4); and because nails were at 3-foot intervals, any warp caused a leak. Boards in the board-and-batten siding were not held in place as tightly as tongue-and-groove boards and therefore warped more. Furthermore, after the boards and battens were dressed on one side and installed on the girts, the sawn faces of adjacent boards were not always in the same plane. Thus, a batten might be tight to one board but not to the other, and a leak would result.

Horizontal clapboard, planed on one face only and installed with the rough-sawn face to the weather, leaked even more than the board-and-batten siding. Every joint showed light between the rough exterior face of one board and the dressed interior face of the board above in both the red oak and yellow-poplar panels (fig. 10), and wetting was evident on the inner faces after rains.

Water staining and wetting of the inner faces of the panels was also associated with the number of butt joints in the siding, regardless of style. Although boards were butted as tightly as possible during installation, some of these joints separated. Thus, in panels containing shorter than full-length boards there was more water staining than in panels of 12-foot boards.

Besides leakage, nail popping and splitting differed among siding styles. Board-and-batten siding had more pops and splits than the other two styles. The splits were most frequent in the battens, partly because of longitudinal shrinkage and stress concentration around the nail holes.

Treatment Differences

The water-repellent penta treatment was better than penta or no treatment for reducing leaks and splits but did not always

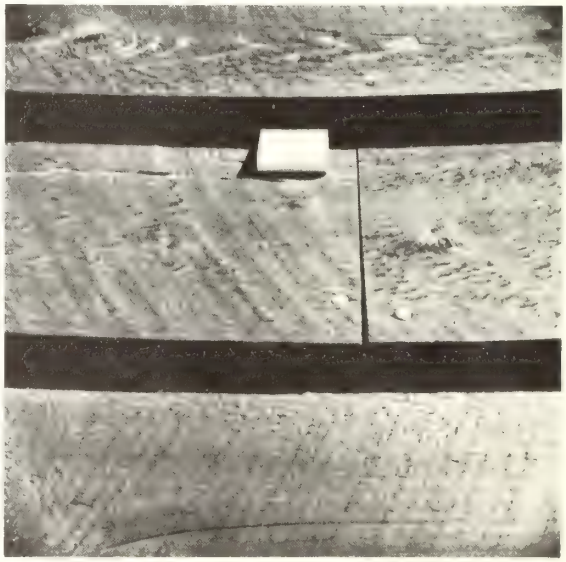

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Figure 10.—This yellow-poplar horizontal clapboard siding joint was open about 1/8 inch.

Table 3.—Frequency and type of failure of untreated and treated hardwood siding (north and south walls)

Type of treatment	Types of failures			
	Leaks[1/]	Splits[2/]	Nail pops[3/]	Checks[4/]
	Percent failures			
Penta and water repellent	5	8	3	45
Penta	10	14	3	40
No treatment	12	13	4	50

1/ Length of leaky joints between boards divided by total length of joints between boards x 100.

2/ Total length of splits over 4 inches long divided by total length of boards in panels x 100.

3/ Number of popped nails divided by total number of exposed nail heads in panels x 100.

4/ Number of square feet of checked panels divided by total square feet in panels x 100. Exterior side only.

retard nail popping and checking (table 3). Differences in performance were small between penta and no treatment. However, because of interactions between species and treatments, treatment effect is best understood by examining differences by species.

Treated yellow-poplar panels had fewer leaks and checks than the untreated panels, but splitting and nail-popping were not reduced by treatment. In the red oak panels leakage and checking apparently were not reduced by treatment. Splitting of red oak boards was least in the penta treated panels and somewhat greater for the untreated and water repellent-penta treated panels. Nail-popping in red oak appeared to be reduced by both treatments. Performance of hickory was not affected by treatment, but penta-treated soft maple had fewer splits and checks. In untreated beech board-and-batten panels nail-popping was less than in the water-repellent treated panel — the only case where a treated panel had more nail pops than an untreated panel. For sycamore there was less nail-popping in the water repellent-penta treated panel, but there was little difference among the other panels.

An outstanding difference due to treatments was the amount of water stain on the inside of the panels (see fig. 11). In all siding the water repellent-penta treated boards were almost free of stain, whereas all the untreated and penta treated panels had considerable stain on the inner faces.

One untreated sycamore board on the north wall had decay near the bottom girt inside the building. Decay also has started in one untreated cottonwood and one untreated ash board (not part of the major test) at both ends of the building. The areas of decay started at barely visible sticker stains and are about 2 inches square. These areas showed incipient decay after 3 years, and after 6 years are very soft.

Another treatment difference occurred in the east gable of board-and-batten elm. Half

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Figure 11.—Water has stained the inner faces of the penta-treated (left) and untreated (right) portions of this red oak mixed-length tongue-and-groove siding. The water-repellent penta-treated portion (center) has no stain. Free water was not observed on any of the portions after rains. Stain is therefore attributed to moisture wicking through butt and edge joints.

the gable was penta-treated and half was untreated. In 1962 woodpeckers attacked the battens. One batten on the treated side had one pecked spot; all battens on the untreated half had several pecked spots at the edges.

As judged by the four performance criteria, the treated panels were better than the untreated panels. If, in addition, water staining on the inside is considered, the water repellent preservative has been the best of the three treatments.

Differences Between the North and South Exposures

The general appearance of the north wall has always been better than that of the south wall. Leaks, splits, nail pops, and checks have been fewer and the finish has faded less.

	Percent of failures	
	North wall	*South wall*
Leaks	8	11
Splits	8	16
Nail pops	2	4
Checks	45	50

Joint leaks on the south wall, initially much more numerous than on the north wall, are now only slightly more numerous but noticeably longer. The longer leaks are due primarily to more nail loosening, warp, and shrinkage (figs. 2 and 4). This is true regardless of species or treatment, but it is more evident in beech and sycamore than in the other species. Furthermore, water stain on the inside was first noticed on the south wall, and it continues to be more extensive there than on the north wall.

Siding Cost Differences

Besides studying siding performance, we recorded costs. Considering our lumber yields, current lumber prices, and estimated labor costs, the red oak and yellow-poplar tongue-and-groove siding cost less ($0.35 and $0.38 per square foot) than board-and-batten siding made of the same woods ($0.37 and $0.41 per square foot) (table 4). But, if low cost is the main criterion, soft maple board-and-batten siding at $0.28 per square foot ranked first, primarily because soft maple No. 1 Common lumber cost the least.

We estimate that yellow-poplar siding cost $0.08 per square foot less than similar siding can be made from Douglas-fir C Select lumber. Furthermore, yellow-poplar tongue-and-groove siding performed well, held a finish satisfactorily, and did not develop raised grain as Douglas-fir sometimes does. Installed ¾-inch Douglas-fir AC exterior plywood siding is estimated to cost about $0.375

Table 4.—Cost of ¾-inch siding by style and species

Style and species	Lumber cost per 1,000 sq. ft.[1]	Milling yield[2]	Per thousand sq. ft. of coverage				Total cost rank
			Required mill input[3]	Material cost	Milling cost[4]	Installation labor costs[5]	Total installed cost	
	Dollars	Percent	Sq. ft.	Dollars	Dollars	Dollars	Dollars	
Board-and-batten								
Red oak	135	61.9	2,019	272.57	24.23	75.00	371.80	6
Yellow-poplar	150	60.0	2,083	312.45	24.97	75.00	412.42	9
Beech	127	62.4	2,003	254.38	24.04	75.00	353.42	5
Hickory	148	75.3	1,660	245.68	19.92	75.00	340.60	3
Sycamore	110	65.9	1,897	208.67	22.76	75.00	306.43	2
Maple	110	74.4	1,678	184.58	20.14	75.00	279.72	1
Tongue-and-groove								
Red oak	135	54.5	1,908	257.58	28.62	65.00	351.20	4
Yellow-poplar	150	53.8	1,993	289.95	29.00	65.00	383.95	8
Douglas-fir	320	85.0	1,176	393.96	0.00	65.00	458.96	10
Plywood								
Douglas-fir	335	100.0	1,000	320.00	0.00	45.00	375.00	7

[1] All 1-inch No. 1 Common lumber except: maple--No. 1 Common, worm holes no defect; Douglas-fir--C Select; and Douglas-fir plywood--AC. Hardwood prices are local mill prices for rough air-dry lumber. Softwood prices are local retail yard prices.

[2] Actual production yields for hardwoods. Softwood yields are estimated from Construction Estimates Guide, 1963.

[3] Anticipates siding milling losses and loss in coverage due to board-and-batten overlap and tongue-and-groove interlocking.

[4] Board-and-batten siding $12.00/M sq. ft.; tongue-and-groove $15.00/M sq. ft.

[5] Carpenter and helper. From Building Construction Cost Data, by Robert S. Means, 1966.

per square foot, which is about the same as our yellow-poplar tongue-and-groove siding cost, and is $0.024 per square foot more than our costs for red oak tongue-and-groove siding.

Recommendations

From this study, the following hardwood siding recommendations are made:

1. For maximum weathertightness use full-length, vertical tongue-and-groove yellow-poplar or red oak siding, dip-treated in a water-repellent preservative, and installed bark side out.

2. If rough vertical board-and-batten or horizontal clapboard siding is preferred, the lumber must be accurately milled to insure boards of the same thickness. To insure tight joints it is better to use boards dressed on both sides and sacrifice the good finish retention provided by rough faces. Red oak and yellow-poplar are both suitable for board-and-batten siding.

3. Where vertical siding is installed on horizontal nailing girts, the girts should be closer than 3 feet on centers, particularly with board-and-batten siding. We recommend placing girts on 2-foot centers.

Some Recent Research Papers of the North Central Forest Experiment Station

Forest Tree Improvement Research in the Lake States, 1965, by Paul O. Rudolf. U.S. Forest Serv. Res. Pap. NC-1, 54 pp. 1966.

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Joint Proceedings, Second Genetics Workshop of the Society of American Foresters and the Seventh Lake States Forest Tree Improvement Conference, October 21-23, 1965, by North Central Forest Experiment Station, U.S. Forest Serv. Res. Pap. NC-6, 110 pp., illus. 1966.

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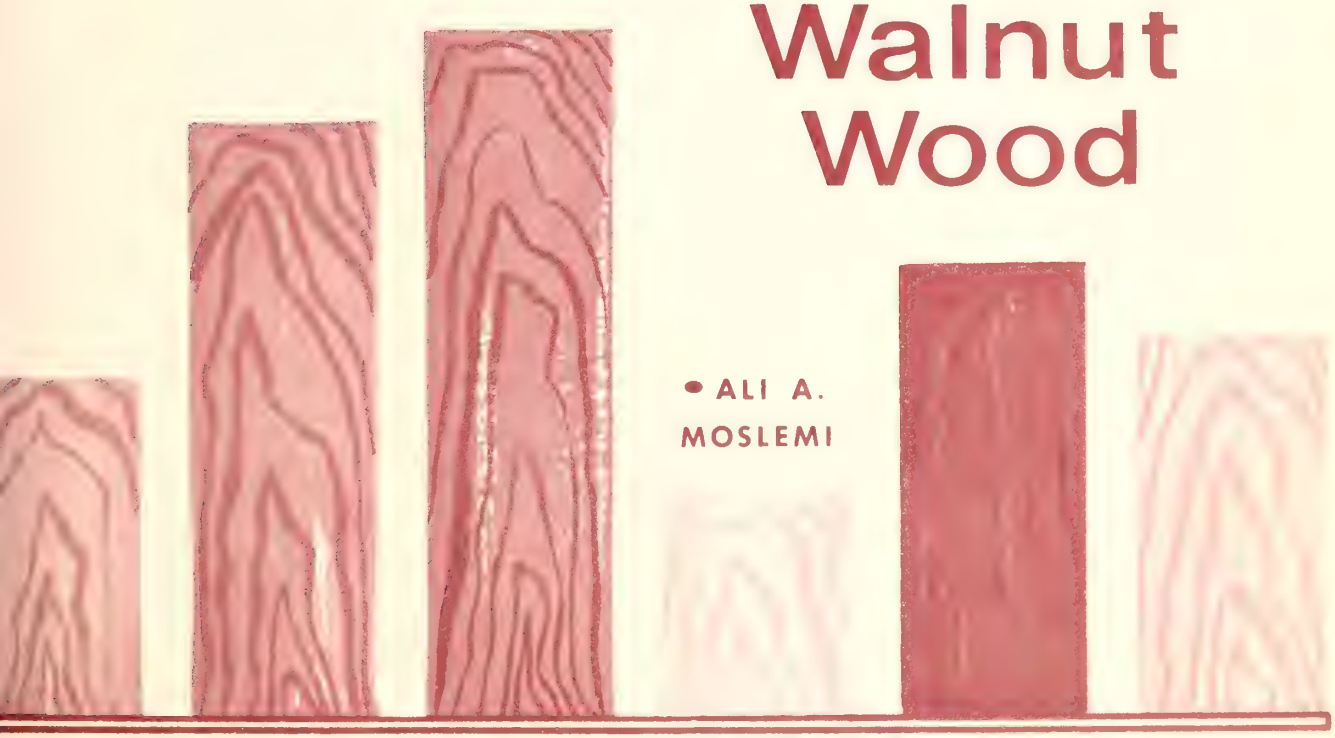
Quantitative Color Measurement for Black Walnut Wood



• ALI A. MOSLEMI

NORTH CENTRAL FOREST EXPERIMENT STATION
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Quantitative Color Measurement for Black Walnut Wood

by
Ali A. Moslemi

Black walnut (*Juglans nigra* L.) wood is well known for its beautiful, warm color. The current demand for black walnut is strong both in the United States and abroad. Top grade logs are much sought after, making individual trees of good quality worth several thousand dollars. The great demand coupled with a shrinking supply has stimulated research to find out how to produce high-quality logs in a shorter period of time. To do this, genetic, site, and cultural factors affecting the growth of walnut must be scrutinized and their influence upon the quality of wood determined.

One factor that affects the quality of walnut wood is its color. To specify the influence of various factors on color, a quantitative means of color measurement is essential. But customary visual color evaluations are inconsistent and inaccurate. So there is no reliable means of comparing walnut wood color among trees grown on different sites, nor of evaluating the effect of fertilization on color of black walnut. Neither is there a quantitative means of measuring color changes that might result from finishing, machining, weathering, and steaming walnut which would be useful to the walnut-using industry.

Several walnut-using firms that were queried on the subject agreed that color influences quality of veneer and lumber; however, no consistent answers were received concerning what was needed.

Apparently, then, there is a need for a walnut wood color evaluating technique for both research purposes and industry. Therefore, a study was made to determine whether existing quantitative color measurement methods could be utilized. The initial study, reported here, showed that walnut wood color can be evaluated by the international CIE (Commission Internationale de Eclairage) method. It was further shown that these walnut wood color data can be expressed in terms of the Munsell color notation. The study also pointed out that the natural hue differences in black walnut wood do not vary greatly but luminosity does. It was, therefore, concluded that luminosity can be used to discriminate color in walnut wood.

The Study

A review of pertinent literature and of color evaluating methods and equipment revealed that information on wood colorimetry in general is limited (Moon and Spencer 1945, Nakamura and Tackachio 1960, Resch and Dost 1965, Sandermann and Schlumbom 1962, Shibamoto *et al.* 1960) and that a nonvisual color evaluating technique would have to be used with walnut (Gray 1961, Loos and Coppock 1964). Twenty randomly selected 5- by 5-inch walnut veneer specimens were sent to a commercial laboratory for spectrophotometric analysis. Reflectance data were obtained for each veneer sample over the visual wavelength spectrum ranging from 400 to 700 millimicrons (400-700 mu).

In some types of color analyses, one may be interested only in color differences between a standard and one or more samples. So one of a second set of four 5- by 5-inch walnut veneer samples was arbitrarily chosen as a standard with which the color of three other veneer samples was compared. These comparisons were made at a second commercial laboratory with a Hunterlab color and color-difference meter.

Methods Used in the Study

Color Analysis

One of the systems used for evaluating color is the CIE system, sometimes referred to as the ICI (International Commission on Illumination) system. To use this system, spectrophotometric color data must be transformed to so-called tristimulus values.[1] These values represent the amounts of the three primary lights or primary colors required in combination to match the color being analyzed. Tristimulus values are usually symbolized by letters X, Y, and Z.

To obtain X, Y, and Z, assume H is the amount of light from the visible spectrum (400-700 mu)

[1] *Because the specialized terminology used in this paper may not be familiar to many of the readers, a glossary of technical terms appears on inside back cover.*

striking a unit area of the object; then within the small wavelength interval $\Delta\lambda$ the amount of light striking the object per unit area will be equal to $H\Delta\lambda$. The reflected light entering the observer's eye from an opaque object (such as wood) would be $RH\Delta\lambda$ in which R represents the relative spectral reflectance of the material. The tristimulus values of the reflected light entering the eye are computed by $RH\bar{x}\Delta\lambda$ for all wavelengths in which $\bar{x}$ (or $\bar{y}$ or $\bar{z}$) is a weighting function. By adding these computed values for all of the visual spectrum, the tristimulus values are obtained. These can be written as follows:

$$X = C \sum_{\lambda=400}^{700} RH\bar{x}\Delta\lambda \qquad (1)$$

$$Y = C \sum_{\lambda=400}^{700} RH\bar{y}\Delta\lambda \qquad (2)$$

$$Z = C \sum_{\lambda=400}^{700} RH\bar{z}\Delta\lambda \qquad (3)$$

in which

$$C = 100 / \sum_{\lambda=400}^{700} H\bar{y}\Delta\lambda \qquad (4)$$

This method of computing tristimulus values is called the weighted-ordinate method because each ordinate of the reflectance curve ($RH\Delta\lambda$) is weighted by $\bar{x}$, $\bar{y}$, and $\bar{z}$ for a given wavelength (fig. 1).

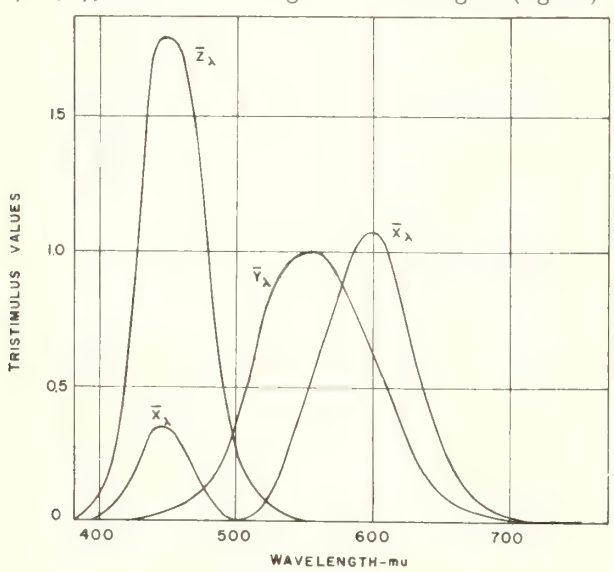


Figure 1.—The weighting functions for the standard observer over the visible wavelengths as recommended by the International Commission on Illumination in 1931. Note that $\bar{x}$ has two maxima.

Published tables (Judd and Wyszecki 1963) of $\bar{x}$, $\bar{y}$, and $\bar{z}$ values are available for various standard illumination sources.

When the values of X, Y, and Z are obtained, they can be converted to specify the x and y chromaticity coordinates which locate the wood hue being analyzed on the CIE color chart:

$$x = \frac{X}{X+Y+Z} \qquad (5)$$

$$y = \frac{Y}{X+Y+Z} \qquad (6)$$

With the values of these coordinates, the color can be plotted and specified.

Color Difference Analysis

The color difference analysis requires that both chromaticness and luminosity be combined for a given sample. This is advantageous for analyzing walnut wood color because, as noted later in this report, walnut does not vary much in chromaticness but exhibits significant variations in luminosity. Color differences among samples can be calculated from the spectrophotometric data. Scofield (1943) specifies the following equation for calculating color differences:

$$\Delta E = \sqrt{(L_s - L_g)^2 + (a_s - a_g)^2 + (b_s - b_g)^2}^{1/2} \qquad (7)$$

in which

$$L_s = 10Y_s^{1/2} \qquad (8)$$
$$a_s = 7L_s\alpha_s \qquad (9)$$
$$b_s = 7L_s\beta_s \qquad (10)$$

are parameters for a standard color sample and

$$L_g = 10Y_g^{1/2} \qquad (11)$$
$$a_g = 7L_g\alpha_g \qquad (12)$$
$$b_g = 7L_g\beta_g \qquad (13)$$

are corresponding parameters for a sample to be compared with the standard. In the above equations Y is a tristimulus value given by Equation 2; α and β are computed as follows:

$$\alpha = \frac{2.4266x - 1.3631y - 0.3214}{x + 2.2633y + 1.1054}$$

and

$$\beta = \frac{0.5710x + 1.2447y - 0.5708}{x + 2.2633y + 1.1054}$$

In these equations, x and y are the chromaticity coordinates as given by Equations 5 and 6. The constants used above are given by Hunter (1941).

Conversion to Munsell System

The spectrophotometric color data can be converted to Munsell color notation in terms of hue, value, and chroma. In the Munsell system (Anon. n.d.), the value parameter specifies the degree of brightness (or darkness) of a color as compared to a neutral gray. Theoretically, value can range from pure black (designated as 0/) to pure white (designated as 10/). Therefore, light colors have a value greater than 5/ while dark colors have values less than 5/. The walnut veneer samples, as noted later in this report, had values ranging approximately from 4/ to 6/.

The chroma parameter specifies the strength of a particular hue. In other words, a chroma value shows how far a given hue departs from neutral gray with the value remaining constant. Numbers assigned to various chromas range from zero to 14 or more (usually designated as /0, /14, etc.). The complete notation for a given color in the Munsell system is written in the following order and manner:

Hue, Value/Chroma.

Thus, a color with a Munsell notation of 2.5YR 6/10 denotes the exact location of a yellowish-red color in the three-dimensional Munsell color space (fig. 2).

Tables and charts for color data conversion from CIE to Munsell, or vice versa, have been prepared (Glenn and Killian 1940, Kelly *et al.* 1943, Kramer 1950, Nickerson 1946, Richmond and Harrison 1959). Using these sources, walnut wood color can be expressed in either CIE or Munsell notation.

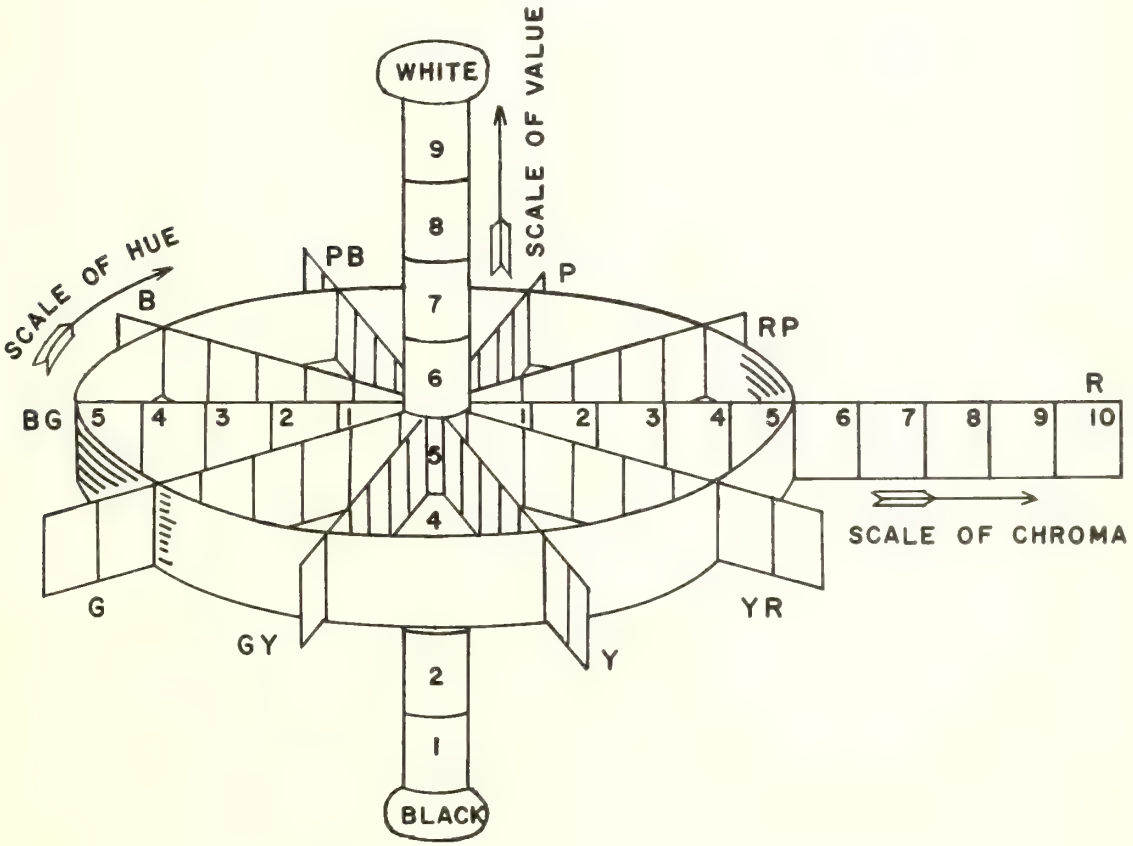


Figure 2.—The Munsell color space showing the three dimensional nature of color specification. The walnut veneer samples ranged in value from approximately 4/ to 6/ on the central axis of this figure. All values in the vertical axis can be expanded in terms of hue and chroma as illustrated for the value of 5/ in the figure.

Results and Discussion

Walnut wood best reflects longer wavelengths in the visible spectrum (orange, red). Other studies (Loos and Coppock 1964, Moon and Spencer 1948) conducted on reflectance characteristics of walnut demonstrated similar results.

The CIE Analysis

Using the data shown in figure 3 and utilizing Equations 1 through 4, the tristimulus values for 20 walnut veneer samples were calculated. The reflectance values of the samples were obtained from the spectrophotograms (fig. 3) and $H\bar{x}\lambda$, $H\bar{y}\lambda$, and $H\bar{z}\lambda$ were obtained from published tables from several sources (Judd 1952, Judd and Wyszecki 1963, Wright 1958). An illustration of how the calculations were made to obtain the tristimulus values (X, Y, Z) for one specimen when the light source is equivalent to average daylight (standard source C) is outlined in table 1. The chromaticity coordinates (x, y) for the walnut veneer specimens were calculated (Equations 5 and 6) as shown at the bottom of table 1. These calculations can be made automatically by some instruments equipped with computers (Loos and Coppock 1964).

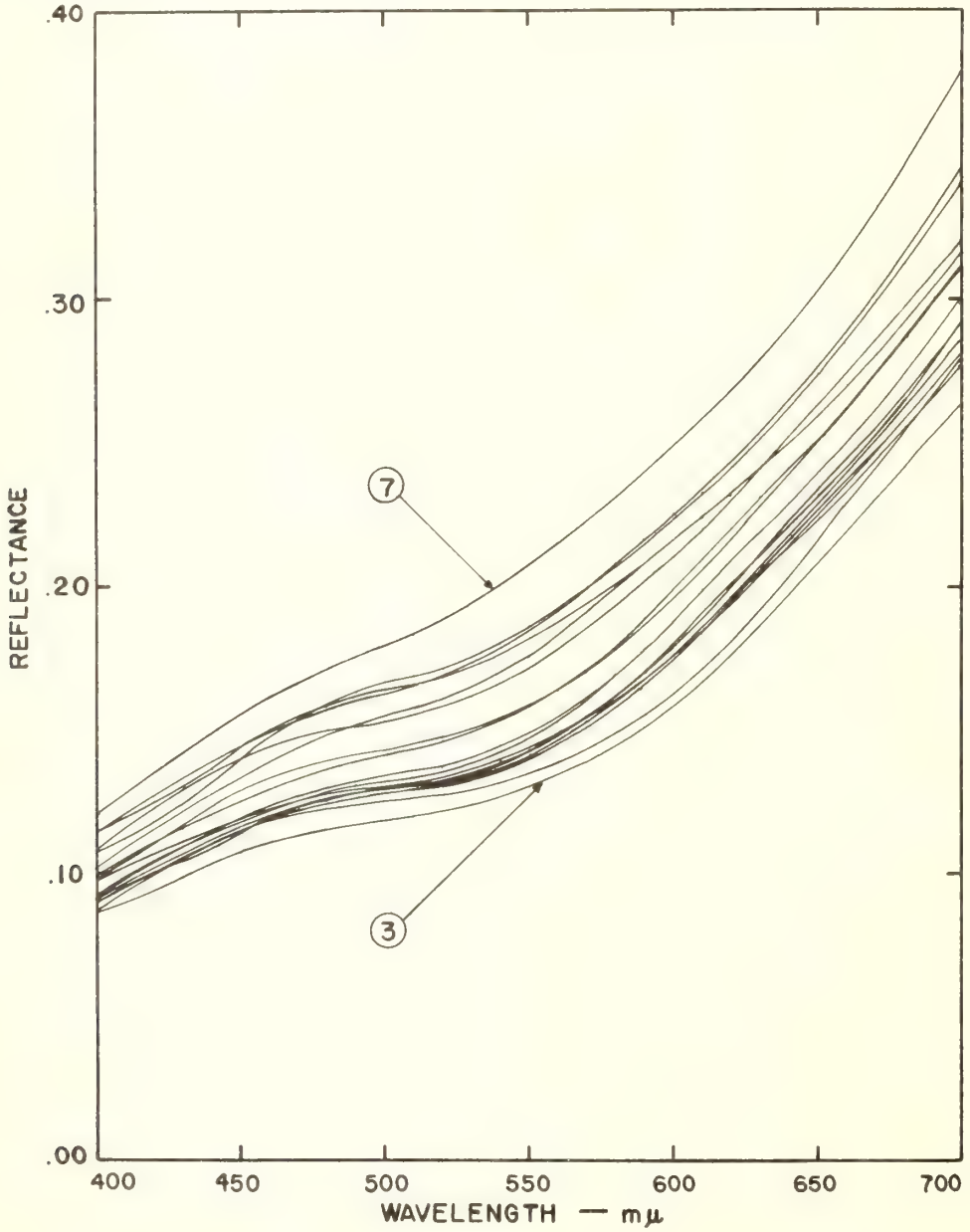


Figure 3.—The reflectance data obtained from 20 walnut veneer specimens. The specimen numbers with the highest and lowest reflectance characteristics are indicated. Note that walnut wood generally best reflects lights of long wavelengths.

Table 1.—*Sample calculation for determining the tristimulus values and chromaticity coordinates for walnut veneer specimen No. 1 using illumination source C*

Wavelength mu	R	$\bar{x}H\lambda$	$R\bar{x}H\lambda$	$\bar{y}H\lambda$	$R\bar{y}H\lambda$	$\bar{z}H\lambda$	$R\bar{z}H\lambda$
400	.088	.085	.075	.002	.000	.404	.036
410	.096	.329	.032	.009	.001	1.570	.151
420	.099	1.238	.123	.037	.004	5.949	.589
430	.105	2.997	.315	.122	.013	14.628	1.536
440	.110	3.975	.437	.262	.029	19.938	2.193
450	.116	3.915	.454	.443	.051	20.638	2.394
460	.119	3.363	.400	.694	.083	19.299	2.297
470	.121	2.272	.275	1.058	.128	14.972	1.812
480	.123	1.112	.137	1.618	.199	9.461	1.164
490	.124	.362	.045	2.358	.292	5.274	.654
500	.125	.052	.007	3.401	.425	2.864	.358
510	.126	.089	.011	4.833	.609	1.520	.192
520	.127	.576	.073	6.462	.821	.712	.090
530	.128	1.523	.195	7.934	1.016	.388	.050
540	.131	2.785	.365	9.149	1.199	.195	.026
550	.133	4.282	.570	9.832	1.308	.086	.011
560	.139	5.880	.817	9.841	1.368	.039	.005
570	.142	7.322	.104	9.147	1.299	.020	.003
580	.149	8.417	1.254	7.992	1.191	.016	.002
590	.156	8.984	1.402	6.627	1.034	.010	.002
600	.162	8.949	1.450	5.316	.861	.007	.001
610	.172	8.325	1.432	4.176	.718	.002	.000
620	.180	7.070	1.273	3.153	.568	.002	.000
630	.192	5.309	1.019	2.190	.420	.000	.000
640	.206	4.693	.761	1.443	.297	.000	.000
650	.220	2.349	.517	.886	.195	.000	.000
660	.230	1.361	.313	.504	.116	.000	.000
670	.242	.708	.171	.259	.063	.000	.000
680	.255	.369	.094	.134	.034	.000	.000
690	.269	.171	.046	.062	.017	.000	.000
700	.278	.082	.023	.029	.008	.000	.000
			X=14.190		Y=14.367		Z=13.566

$$x = \frac{14.190}{14.190 + 14.367 + 13.566} = 0.337$$

$$y = \frac{14.367}{14.190 + 14.367 + 13.566} = 0.341$$

$$z = \frac{13.566}{14.190 + 14.367 + 13.566} = 0.322$$

The tristimulus values do, of course, depend on the source of illumination used. In the CIE system, three standard illuminant sources designated as A, B, and C are used. Source A is representative of a gas-filled incandescent lamp that operates at a temperature of 2,848 degrees Kelvin (2,575°C). Source B is equivalent to noon sunlight at about 4,800°K, and source C simulates average daylight at about 6,700°K. (fig. 4). The same color will look somewhat different under these three standard sources (fig. 5). Source C is often used in colorimetric studies. Sources A and B are also used in colorimetry because under some circumstances source C may not be the best source to use. For example, source A, representing incandescent lamps, shows how walnut color appears under artificial lighting such as at night in a living room. The same applies to source B if one is interested in finding out how walnut color appears under noon sunlight. If a researcher wants to compare the color of a given piece of wood in average daylight and at night under lights, then he needs data obtained by using sources A and C.

The tristimulus values and chromaticity coordinates for the 20 walnut veneer specimens as examined

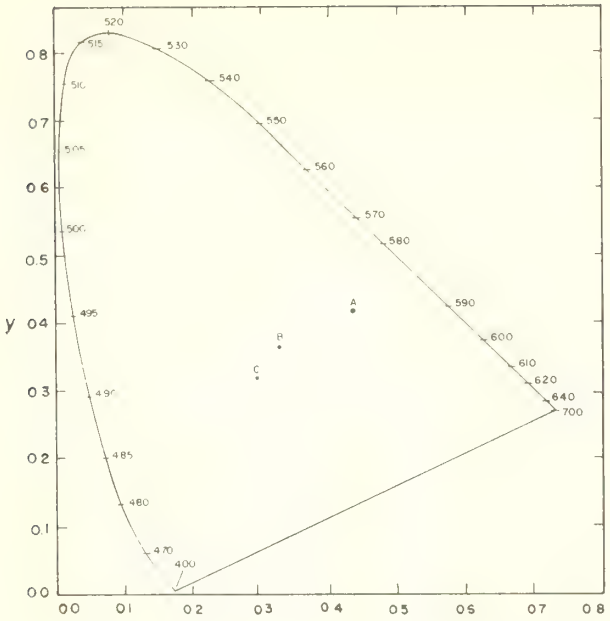


Figure. 4—The CIE color chart showing the location of the standard illumination sources A, B, and C with respect to their accepted hues. Figures on the loop represent wavelength in millimicrons.

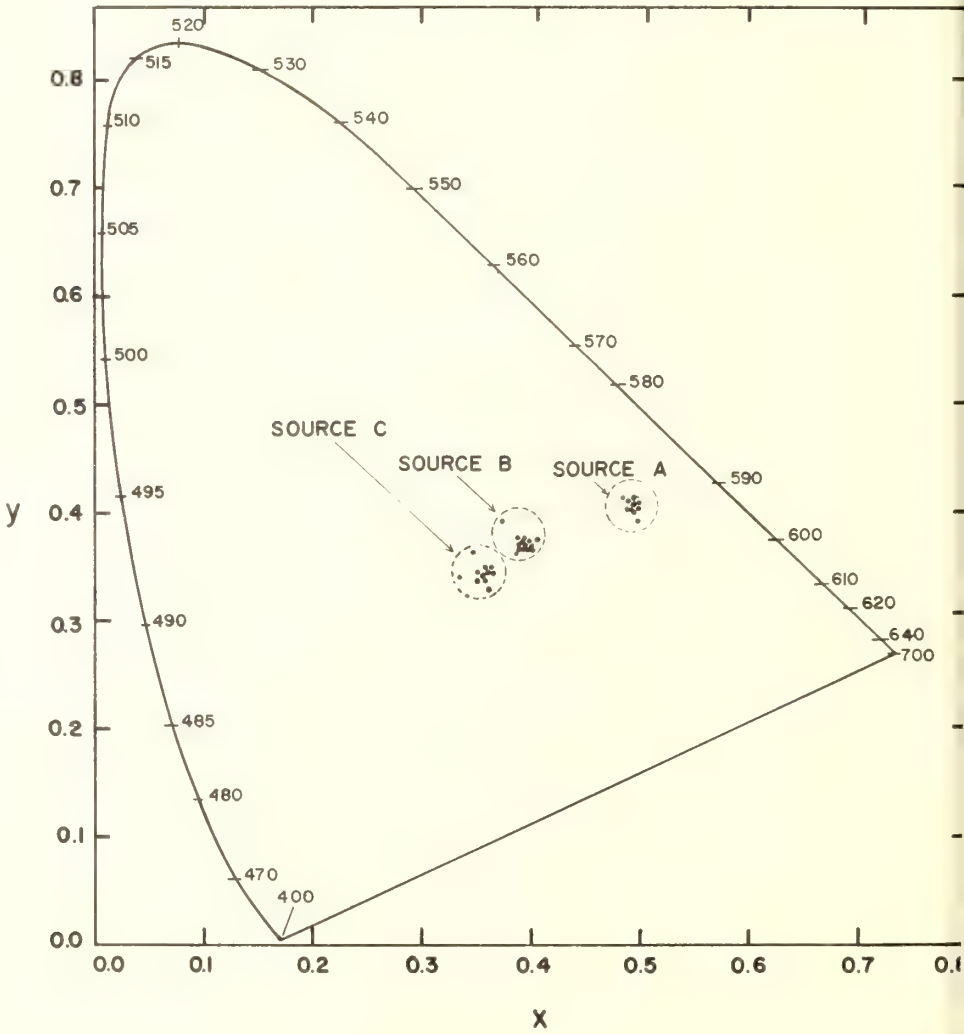


Figure 5.—The plot of walnut veneer hue on the CIE color chart for the test specimens using standard illumination sources A, B, and C. Note that the color of the same veneer specimens appears differently depending upon the source used.

under the three standard illumination sources (A, B, and C) show only small variations within any one of the chromaticity coordinates (see tables 2, 3, and 4). This indicates that hue changes among the veneer samples studied were small regardless of illumination source used. With light source C the color differences were brought out somewhat better than with light sources A or B (fig. 6). Because the hue

Table 2.—*Tristimulus values and chromaticity coordinates for 20 walnut veneer specimens using illumination source A*

Specimen	Tristimulus values			Chromaticity coordinates		
No.	X	Y	Z	x	y	z
1	18.365	15.108	4.154	.488	.402	.110
2	19.630	16.178	4.321	.489	.403	.108
3	17.914	14.754	3.876	.490	.404	.106
4	21.843	17.908	4.667	.492	.403	.105
5	19.689	16.133	4.179	.492	.403	.104
6	19.929	16.274	4.235	.493	.402	.105
7	27.442	22.898	5.754	.489	.408	.103
8	21.883	17.924	4.584	.493	.404	.103
9	19.410	15.919	4.210	.491	.403	.106
10	20.703	16.926	4.337	.493	.403	.103
11	19.926	16.271	4.192	.493	.403	.104
12	24.711	20.490	5.268	.490	.406	.104
13	23.244	18.282	5.080	.499	.392	.109
14	23.580	19.633	4.924	.490	.408	.102
15	23.732	19.955	5.272	.485	.408	.108
16	24.691	20.640	5.199	.489	.408	.103
17	20.740	16.923	4.308	.494	.403	.103
18	19.724	16.208	4.203	.491	.404	.105
19	21.910	18.169	4.615	.490	.407	.103
20	22.363	18.354	4.557	.494	.405	.101

Table 3.—*Tristimulus values and chromaticity coordinates for 20 walnut veneer specimens using illumination source B*

Specimen	Tristimulus values			Chromaticity coordinates		
No.	X	Y	Z	x	y	z
1	15.672	14.567	9.837	.391	.363	.245
2	16.740	15.578	10.229	.393	.366	.240
3	15.258	14.189	9.157	.395	.368	.237
4	18.565	17.205	11.024	.397	.368	.236
5	16.729	15.499	9.972	.396	.367	.236
6	16.899	15.612	10.000	.398	.367	.235
7	23.401	22.074	13.560	.396	.374	.230
8	18.578	16.993	10.821	.400	.365	.233
9	16.332	15.286	9.962	.393	.368	.240
10	17.567	16.237	10.242	.399	.369	.233
11	16.900	15.603	9.889	.399	.368	.233
12	21.077	19.725	12.435	.396	.371	.234
13	17.524	18.585	11.028	.372	.394	.234
14	20.095	18.914	11.587	.397	.374	.229
15	20.342	19.314	12.425	.391	.371	.239
16	21.039	19.925	12.190	.396	.375	.229
17	17.589	16.216	10.175	.400	.369	.231
18	16.771	15.581	9.922	.397	.369	.235
19	18.670	17.493	10.877	.397	.372	.231
20	18.977	17.597	10.753	.401	.372	.227

Table 4.—*Tristimulus values and chromaticity coordinates for 20 walnut veneer specimens using illumination source C*

Specimen No.	Tristimulus values			Chromaticity coordinates		
	X	Y	Z	x	y	z
1	14.190	14.367	13.566	.337	.341	.322
2	16.071	15.752	14.112	.350	.343	.307
3	14.624	13.225	12.622	.361	.327	.311
4	17.791	16.949	15.193	.356	.339	.304
5	16.017	15.270	13.608	.357	.340	.303
6	16.196	15.381	13.796	.357	.339	.304
7	22.421	21.768	18.669	.357	.346	.297
8	17.777	16.940	14.192	.363	.346	.290
9	15.836	15.078	13.736	.355	.338	.308
10	16.802	15.989	14.096	.358	.341	.301
11	16.178	16.831	13.631	.347	.361	.292
12	20.207	19.444	17.145	.356	.342	.302
13	19.003	18.203	16.591	.353	.338	.308
14	19.246	18.641	15.944	.358	.346	.296
15	19.555	19.080	17.123	.351	.342	.307
16	20.152	19.655	16.757	.356	.347	.296
17	16.759	15.960	14.021	.359	.341	.300
18	16.069	15.347	13.674	.356	.340	.303
19	17.886	17.241	14.982	.357	.344	.299
20	18.147	17.320	14.817	.361	.344	.295

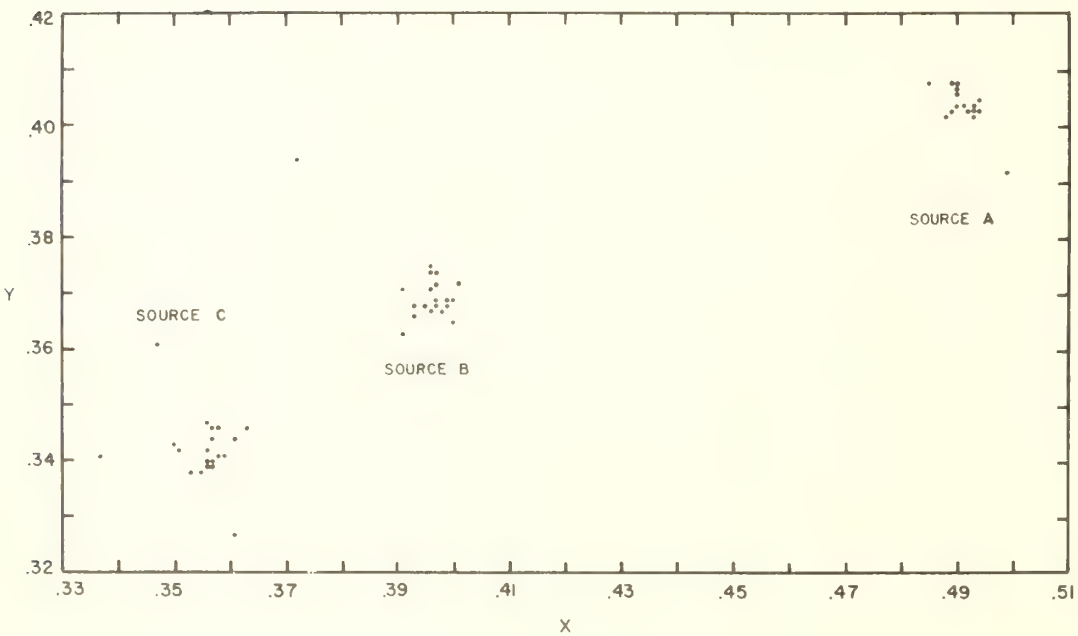
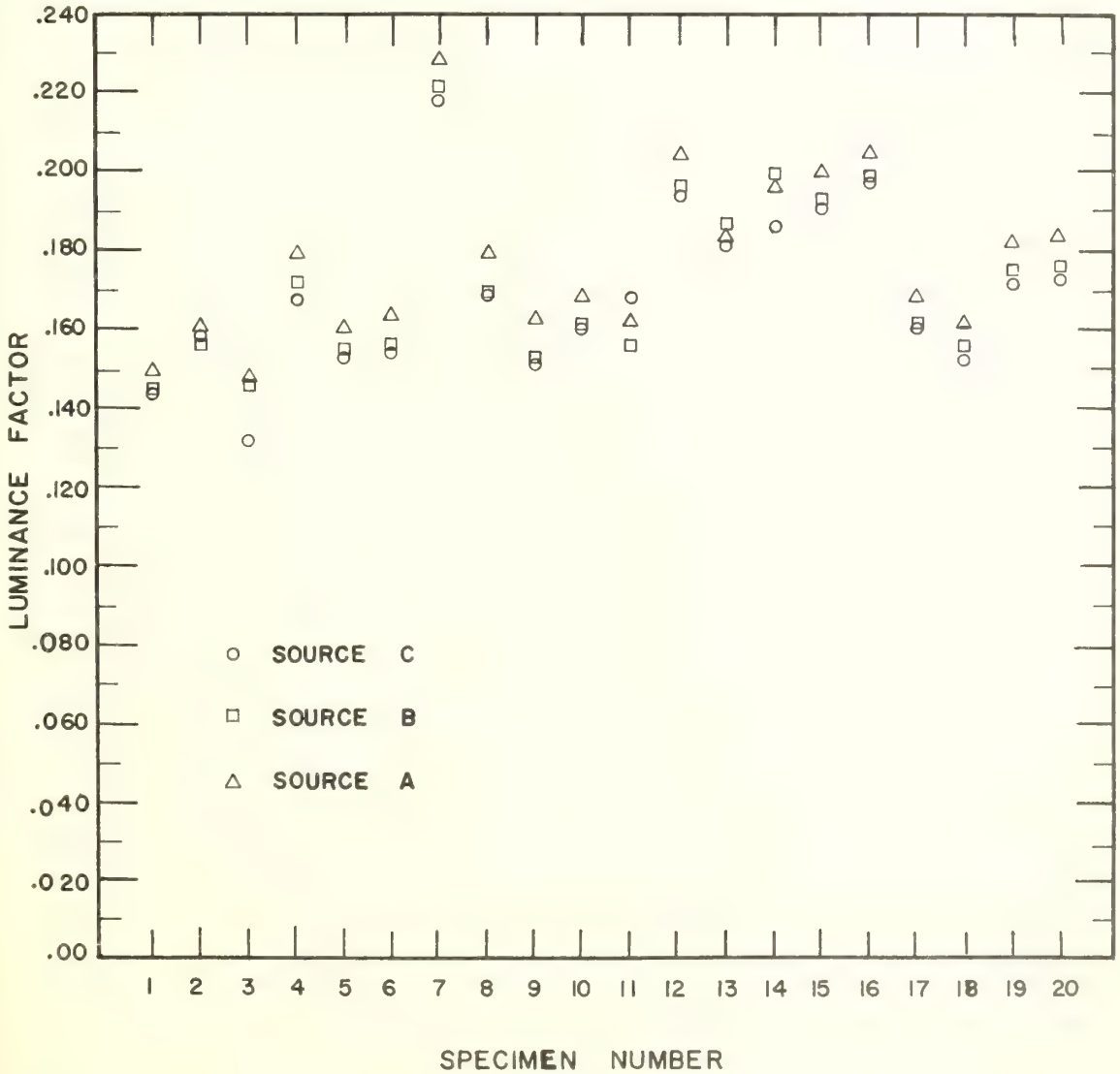


Figure 6. — The expanded plot of the CIE color chart showing walnut wood color points in detail for standard sources A, B, and C. Under source C the color data for walnut show more scatter, thus making this source more discriminating.

points were more widely scattered with light source C, this source appears to be best suited for evaluating hue differences.

Our study also indicated that the color luminance varied among the samples studied. Assuming the luminance of a perfectly reflecting surface as 1.0 then the luminance of study specimens is expressed as a fraction of 1.0. This value, termed the Luminance Factor (Wright 1958), is calculated by using Equation 2. The variations in luminance among the 20 specimens and within light sources were relatively large indicating that the Luminance Factor can be used in discriminating walnut wood color (fig. 7).

Figure 7.—Luminance Factor for walnut veneer specimen for standard illumination sources A, B, and C. This parameter shows significant scatter, thus appears to discriminate well for walnut wood color.



Walnut Color in Munsell System

As indicated earlier, the CIE color notation can be converted to the Munsell notation or vice versa. A series of charts for the various Munsell values have been prepared by a subcommittee of the Optical Society of America and are in wide use (Anon. 1943). A separate chart has been made for each value of the Munsell notation. These charts are composed of the CIE chromaticity chart on which Munsell hue and chroma have been plotted. The value for the Munsell notation can be obtained from data prepared by the Optical Society of America if the Y value in the CIE system is known.

The method of calculating the Munsell color notation for light source C is outlined below using the data for one veneer sample as an example.

1. The CIE data for specimen No. 1 are (table 4):
   Y=14.37 x=0.337 y=0.341
2. Using Y=14.37, the Munsell value is 4.34 (Nickerson 1946).
3. The value level indicates that conversion charts for value levels 4/ and 5/ are both needed. The hue for value 4/ is slightly over 2.5Y (fig. 8) and for value 5/ it is 2.5Y (fig. 9). In this case, 2.5Y is accepted as the hue notation.

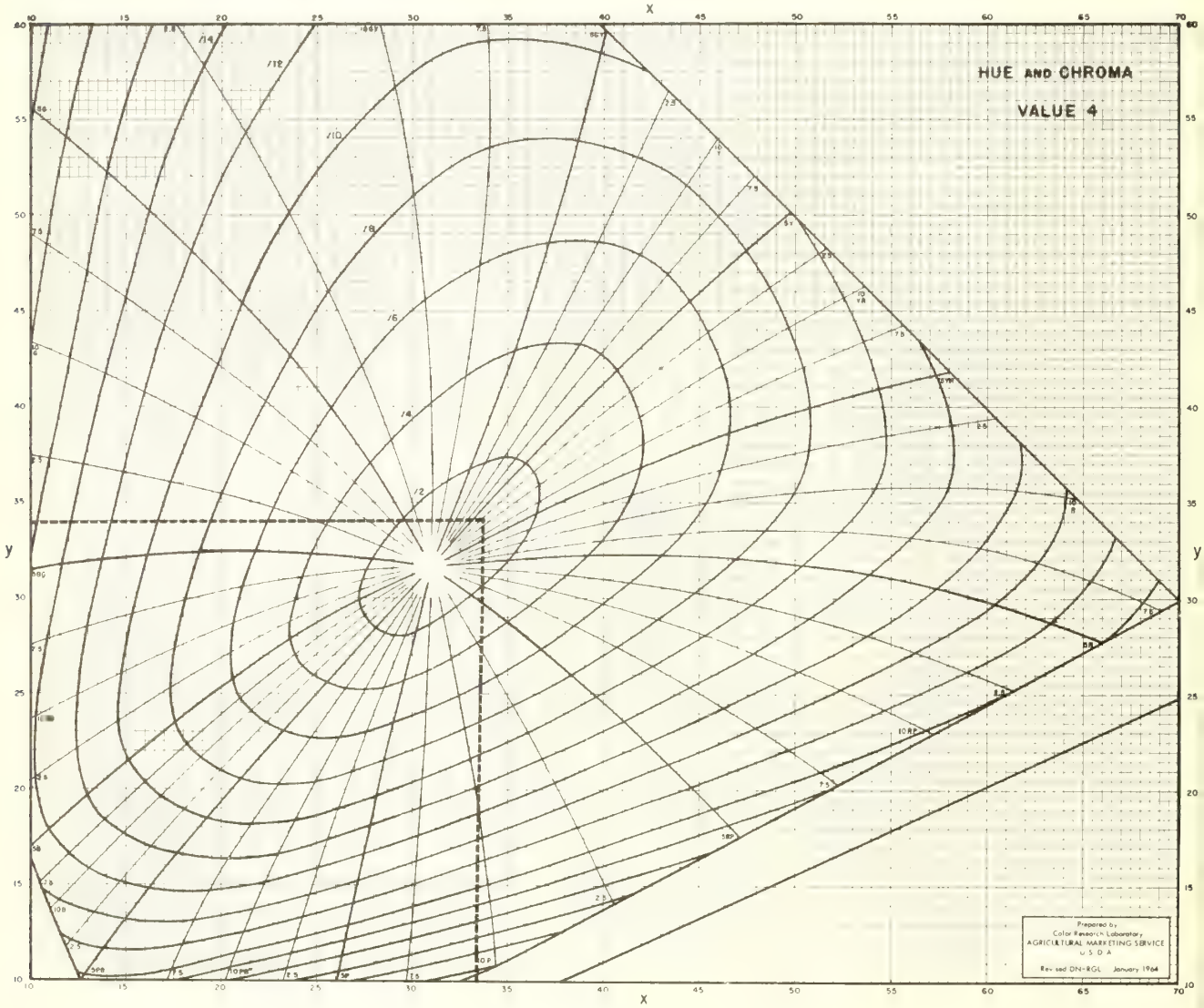


Figure 8.—Conversion chart from CIE to Munsell system for value 4/. This figure shows the loci of constant hue and constant chroma in CIE (x, y) coordinates. The conversion method for specimen No. 1 is shown (also see figure 9). (Reprinted with permission, Newhall, Nickerson, and Judd, J. Opt. Soc. Am. 33, 390, 391 (1943).)

4. The chroma (figs. 8 and 9) is less than /2. Reading the chroma is difficult on these small-scale charts but easy-to-read large-scale charts are available.

Table 5 lists the Munsell values and hues of the walnut veneer specimens as determined by using this method.

Color Difference Measurement

In some cases, one may be interested in determining what differences exist among the colors in a group of specimens when a standard is used. For example, a researcher may wish to determine the differences in color between the wood of a control tree with trees of the same species that have undergone a special treatment, such as fertilization or release. Other examples would be determining the effect of machining, finishing, weathering, or steaming on the color of wood by comparing the colors before and after such treatments. Equation 7 can be used to analyze color differences. This equation takes both luminance and chromaticness into account.

The Hunterlab color and color difference meter is one instrument that can be used to quantify color differences. The instrument specifies color differences in a three-dimensional space system (fig. 10). With

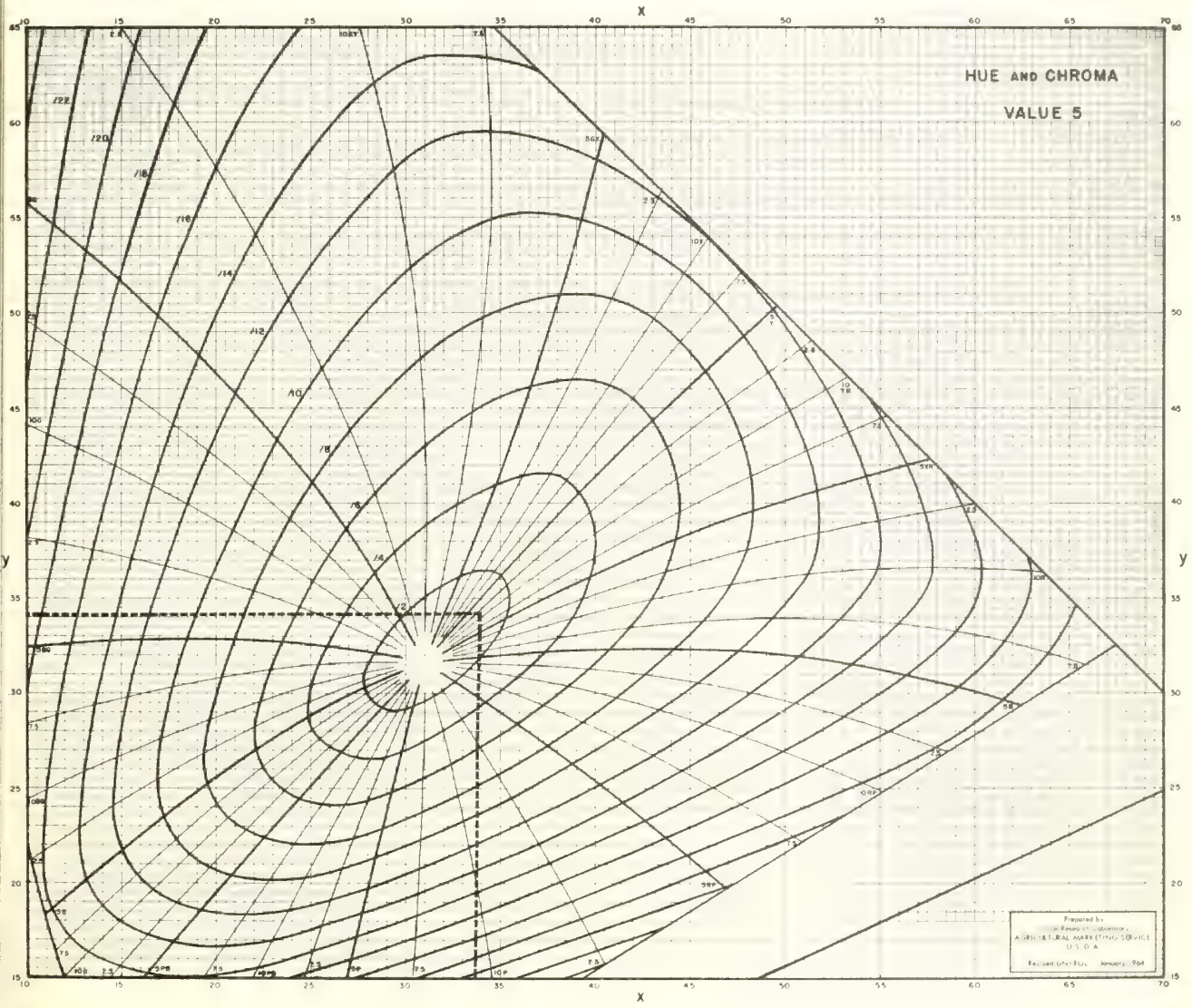


Figure 9.—Conversion chart from CIE to Munsell system for value 5/. The conversion method for specimen No. 1 is shown (also see figure 8). (Reprinted with permission, Newhall, Nickerson, and Judd, J. Opt. Soc. Am. 33, 390, 391 (1943).)

Table 5.—*Munsell color notation for 20 walnut veneer specimens as obtained from the CIE color data utilizing illumination source C*[1]

Specimen No.	CIE (Y)	Value	Hue[2/]
1	14.37	4.34	2.5YR[3/]
2	15.75	4.52	8.0YR
3	13.23	4.18	8.2R
4	16.95	4.67	5.0YR
5	16.02	4.56	5.0YR
6	15.38	4.48	5.0YR
7	21.77	5.22	7.2YR
8	16.94	4.67	5.5YR
9	15.08	4.44	3.5YR
10	15.99	4.55	5.0YR
11	16.83	4.67	6.0Y
12	19.44	4.96	5.2Y
13	18.20	4.82	5.0YR
14	18.64	4.87	7.5YR
15	19.08	4.92	7.5YR
16	19.66	4.99	7.5YR
17	15.96	4.55	5.6YR
18	15.35	4.47	5.5YR
19	17.24	4.71	6.8YR
20	17.32	4.72	6.2YR

1/ Data on chroma not presented due to gross inaccuracies that would have been caused had small conversion charts available in this study been used.

2/ Data approximate due to the small size of conversion charts used. Presented for illustrative purposes only.

3/ Y = yellow; R = Red.

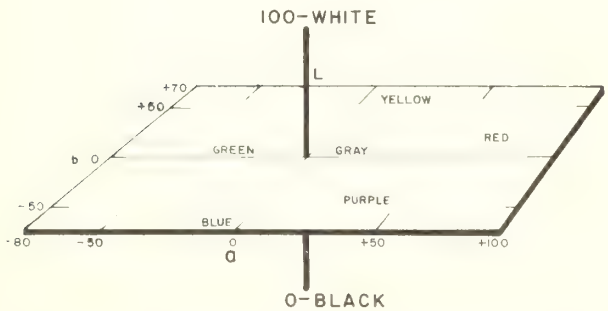


Figure 10.—Color space utilized in color difference specification. This color space was used for walnut veneers studied.

this color meter, using specimen No. 21 as a standard, it was found that the three specimens, as compared with No. 21, contained more blue and purple (fig. 11 and table 6). The results obtained would, of course, differ depending on the standard selected.

Color difference data were also determined mathematically for 20 walnut veneer specimens using CIE color data and Equation 7. Calculations were made using specimen No. 1 as a standard. Computations for specimens No. 1 and 2, as an example, are:

Specimen No. 1:

$Y_1 = 14.4$

$L_1 = 10(14.4)^{1/2} = 38.0$

$$\alpha_1 = \frac{2.4266(0.337) - 1.3631(0.341) - 0.3214}{(0.337) + 2.2633(.341) + 1.1054} = 0.0143$$

$$\beta_1 = \frac{0.5710(0.337) + 1.2447(0.341) - 0.5708}{(0.337) + 2.2633(0.341) + 1.1054} = 0.0208$$

$a_1 = 7(38.0)(0.0143) = 3.804$

$b_1 = 7(38.0)(0.0208) = 5.533$

Specimen No. 2:

$Y_2 = 15.8$

$L_2 = 10(15.8)^{1/2} = 39.4$

$$\alpha_2 = \frac{2.4266(0.350) - 1.363(0.343) - .3214}{(0.350) + 2.2633(0.343) + 1.1054} = 0.0271$$

$$\beta_2 = \frac{.5710(0.350) + 1.2447(0.343) - 0.5708}{(0.350) + 2.2633(0.343) + 1.1054} = 0.0251$$

$a_2 = 7(39.4)(0.0271) = 7.474$

$b_2 = 7(39.4)(0.0251) = 6.923$

$$\Delta E = \left[(38.0 - 36.5)^2 + (3.804 - 7.47)^2 + (5.533 - 6.92)^2\right]^{1/2} = 4.17$$

Table 7 lists the calculated color difference data for the 20 walnut veneer specimens (Specimen Nos. 1-20). In this table data obtained with the Hunterlab color and color difference meter are also included (Specimens Nos. 21-24) this time as compared with specimen No. 1 as a standard. With specimen No. 1 as a standard, most of the 23 remaining veneer specimens fell in the blue-green, green region of the color chart (fig. 12). Parameters *a* and *b* (see Equations 9 and 10) for the walnut specimens were also plotted

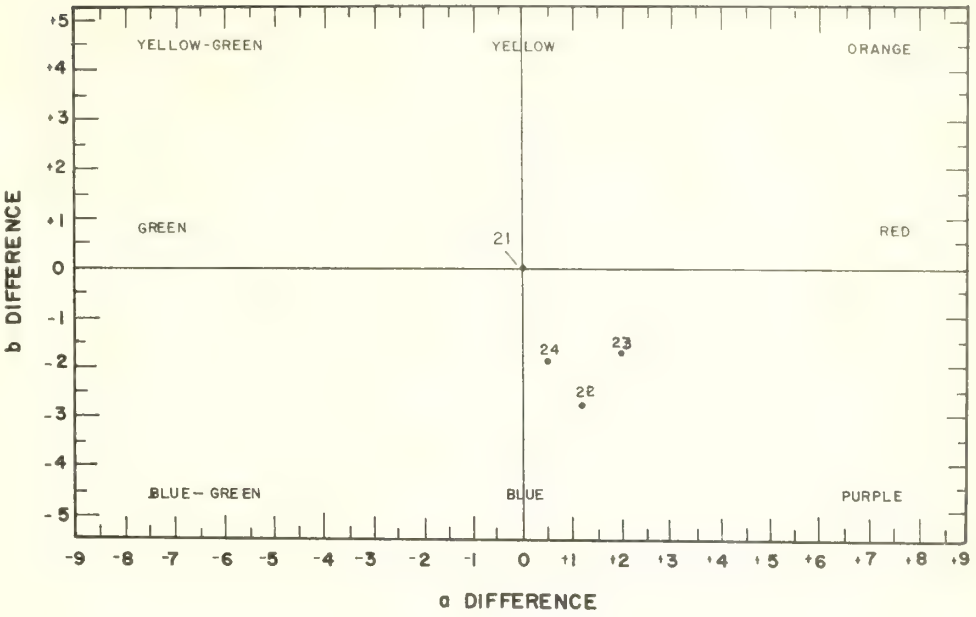


Figure 11.—Color difference graph for four walnut veneer specimens using specimen No. 21 as standard. Data for this graph were obtained by Hunterlab color and color difference meter. This graph indicates that the remaining specimens fell in blue, blue-purple area as compared with specimen No. 21. Specimen numbers are indicated for all points.

(fig. 13). The difference in parameter *a* between the standard and unknown specimens measures redness in relation to the standard when positive and greenness when negative. The difference in parameter *b* between the standard and unknown specimens measures yellowness when positive and blueness when negative. Our 23 walnut specimens as compared to specimen No. 1 appeared greenish and bluish with the exception of specimens 3 (difference in *b*'s positive) and 11 (difference in *a*'s positive). Finally the color difference values ΔE (see Equation 7), with specimen No. 1 as standard were graphed (fig. 14).

Table 6.—*Color difference parameters for 4 walnut veneer specimens as compared to specimen No. 21 and as obtained by Hunterlab color and color difference meter (Light Source C) (see figs. 10 and 11)*

Specimen No.	Color parameters			Parameter differences			Color difference
	L	a	b	L	a	b	ΔE
21	45.1	5.4	9.6	0	0	0	0
22	39.0	6.6	6.8	-6.1	+1.2	-2.8	6.8
23	39.0	7.4	7.9	-6.1	+2.0	-1.7	6.5
24	40.6	5.9	7.7	-4.5	+0.5	-1.9	5.0

Table 7.—*Calculated color difference parameters for 24 walnut veneer specimens as compared with specimen No. 1 utilizing illumination source C*

Specimen No.	Parameters			Differences			Color difference
	L	a	b	L	a	b	ΔE
1	38.0	3.80	5.53	0	0	0	0
2	39.4	7.47	6.92	-1.4	-3.67	-1.39	4.17
3	36.5	12.62	4.91	+1.5	-8.82	+0.62	8.96
4	41.2	10.38	6.92	-3.2	-6.58	-1.39	7.46
5	38.8	10.05	6.79	-0.8	-6.25	-1.29	6.44
6	39.2	10.15	6.86	-1.2	-6.35	-1.33	6.60
7	46.7	10.46	9.48	-8.7	-6.66	-3.95	11.65
8	41.2	11.25	8.08	-3.2	-7.45	-2.55	8.14
9	38.9	9.80	6.54	-0.9	-6.00	-1.01	6.15
10	40.0	10.36	7.28	-2.0	-6.56	-1.75	7.08
11	41.2	3.75	9.52	-3.2	+0.05	-3.99	5.12
12	44.3	10.54	8.06	-6.3	-6.74	-2.53	9.57
13	42.7	10.16	6.87	-4.7	-6.36	-1.34	8.04
14	43.4	10.33	8.51	-5.4	-6.53	-2.93	9.33
15	43.7	8.87	7.65	-5.7	-5.07	-2.12	7.92
16	44.5	9.66	8.72	-6.5	-5.86	-3.19	9.33
17	39.9	10.61	7.54	-1.9	-6.81	-2.01	7.37
18	39.2	9.88	6.86	-1.2	-6.08	-1.33	6.35
19	41.6	9.90	7.86	-3.6	-6.10	-2.33	7.46
20	41.6	11.07	8.15	-3.6	-7.27	-2.62	8.54
21	45.1	5.40	9.60	-7.1	-1.60	-4.07	8.36
22	39.0	6.60	6.80	-1.0	-2.80	-1.27	3.24
23	39.0	7.40	7.90	-1.0	-3.60	-2.37	4.43
24	40.6	5.90	7.70	-2.6	-2.10	-2.17	3.99

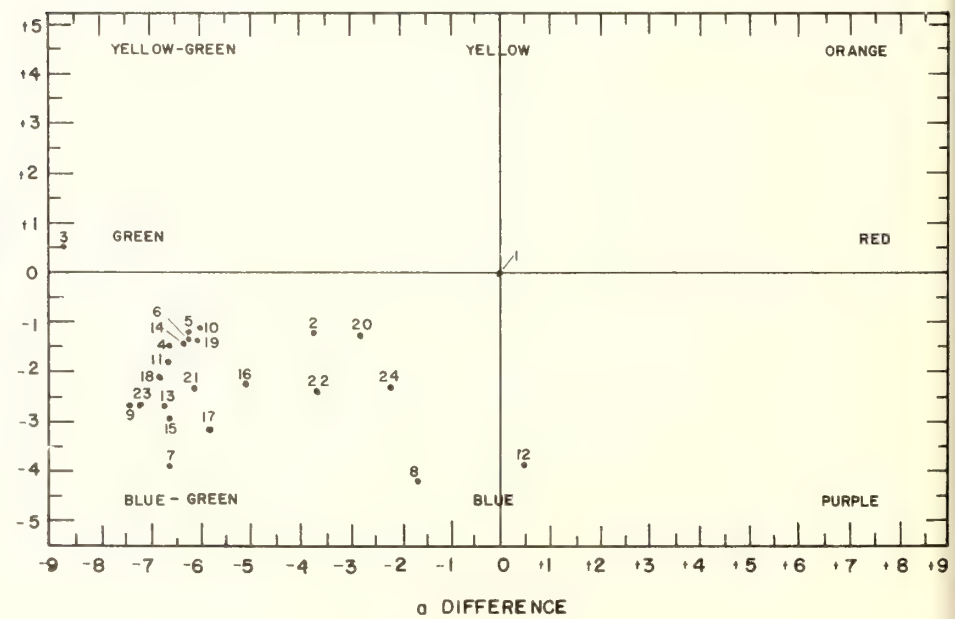


Figure 12.—Calculated color difference graph for 24 walnut veneer specimens as compared with specimen No. 1. Note that almost all remaining specimens fell in the blue-green area of the graph. Specimen numbers are indicated for all points.

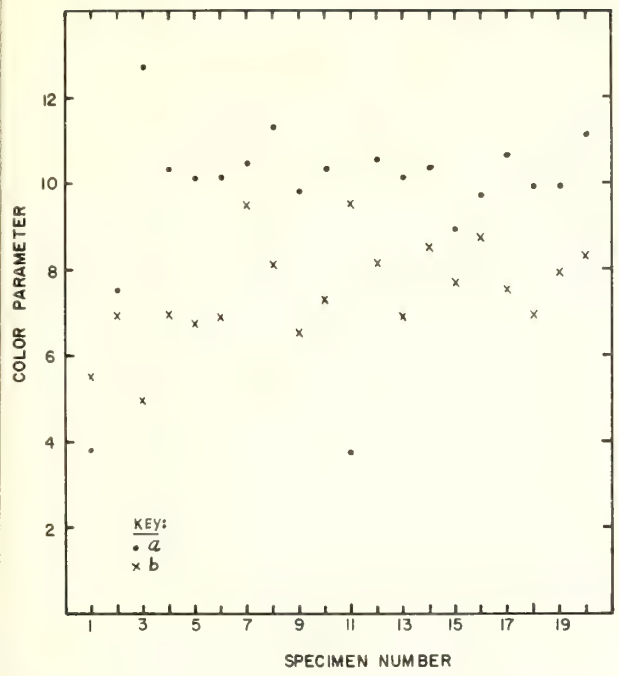


Figure 13.—Color difference parameters *a* and *b* for 20 walnut veneer specimens. The difference between the standard and the given specimen in parameter *a* measures redness when positive and greenness when negative. The difference in parameter *b* measures yellowness when positive and blueness when negative.

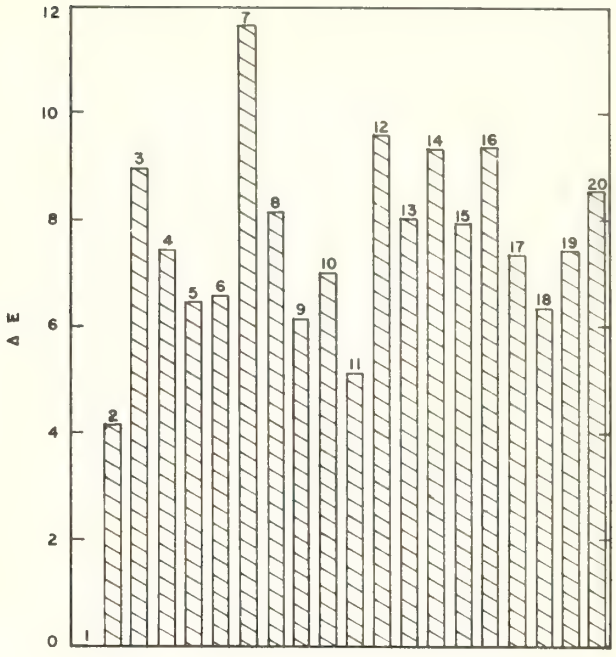


Figure 14.—Color difference values (ΔE) for 20 walnut veneer specimens as defined by Equation 7 in the text. Specimen numbers are indicated.

Conclusions

This study has demonstrated that walnut wood color can be determined quantitatively through spectrophotometric analysis. Although the chromaticity coordinates of walnut wood are not widely different due to little natural hue changes, the luminosity of this wood differs significantly and can be used in discriminating color.

Color notations obtained from the internationally adopted CIE method can be converted to the visual Munsell notation or vice versa which provides considerable freedom for expressing wood color. Also color differences taking into account both chromaticness and luminance can be calculated for walnut wood. These color difference calculations perhaps fulfill our needs best in dealing with wood since it combines both luminance and hue.

The methods for analyzing wood color reported here should generally prove useful in many research applications. These methods can become effective tools for soil scientists and tree geneticists in measuring the influence of environment and inheritance upon the color of wood. Furthermore, consistent color changes within a tree, if any, can be detected. The wood technologist can use the methods described in this report to study color changes due to fading, finishing, weathering, steaming, or bleaching.

Further research in perfecting the science of colorimetry for adaptation to wood is needed. The large color variations due to springwood and summerwood color differences in many species including walnut present a problem which perhaps can be resolved by averaging colors. Or color differences associated with growth rings within a piece of veneer or a board may be expressed in terms of maximum and minimum color values, thus providing a quantitative record for the wood figure. Quantitative color analysis also may prove to be a means of grading figured woods in industry.

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Glossary

Definitions of technical terms as referred to in this report are given below for convenience. Some definitions are based on those prepared by the Committee on Colorimetry of the Optical Society of America.

Combination of colors: Mixing or superimposing lights of different chromaticities.

Chroma: See Munsell chroma.

Chromaticity coordinates: Coordinates (ordinate and abscissa) of a given color to represent it in the chromaticity diagram.

Chromaticness: The quality of color in terms of hue and saturation.

CIE: The initials for Commission Internationale de Eclairage.

CIE chromaticity diagram: An x-y diagram on which chromaticity coordinates are plotted.

CIE coordinate system: The coordinate system used for plotting color using chromaticity coordinates.

Colorimeter: An instrument which is capable of measuring color.

Hue: Represents color as produced by various wavelengths within the visable range of the radiant energy spectrum.

ICI: Initials for International Commission on Illumination, the English language version of CIE.

Luminance factor: A fractional value representing the relative luminosity of colored surface.

Munsell chroma: Saturation as designated in the Munsell method of color measurement.

Munsell hue: That portion of Munsell notation which refers to the hue nature of the given color (see definition of hue above).

Munsell value: Lightness as referred to in the Munsell color notation.

Opaque: Impenetrable to light.

Primary colors: The basic colors whose additive mixtures produce an extensively large variety of colors.

Reflectance: The ratio of reflected light to incident light.

Spectrophotometer: The instrument which measures the spectral reflectance.

Standard observer: A hypothetical observer agreed upon by the CIE in 1931.

Standard Source A: A particular light source representative of artificial illumination recommended by CIE in 1931.

Standard Source B: A particular light source representative of direct sunlight at sea level recommended by CIE in 1931.

Standard Source C: Refers to a particular light source representative of average daylight recommended by CIE in 1931.

Trichromatic colorimetry: Color measurement in terms of mixtures of the three primary colors.

Tristimulus value: Amount of a component necessary in a three-color mixture to match a sample color.

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RESEARCH PAPER NC-18
SEPTEMBER 1967

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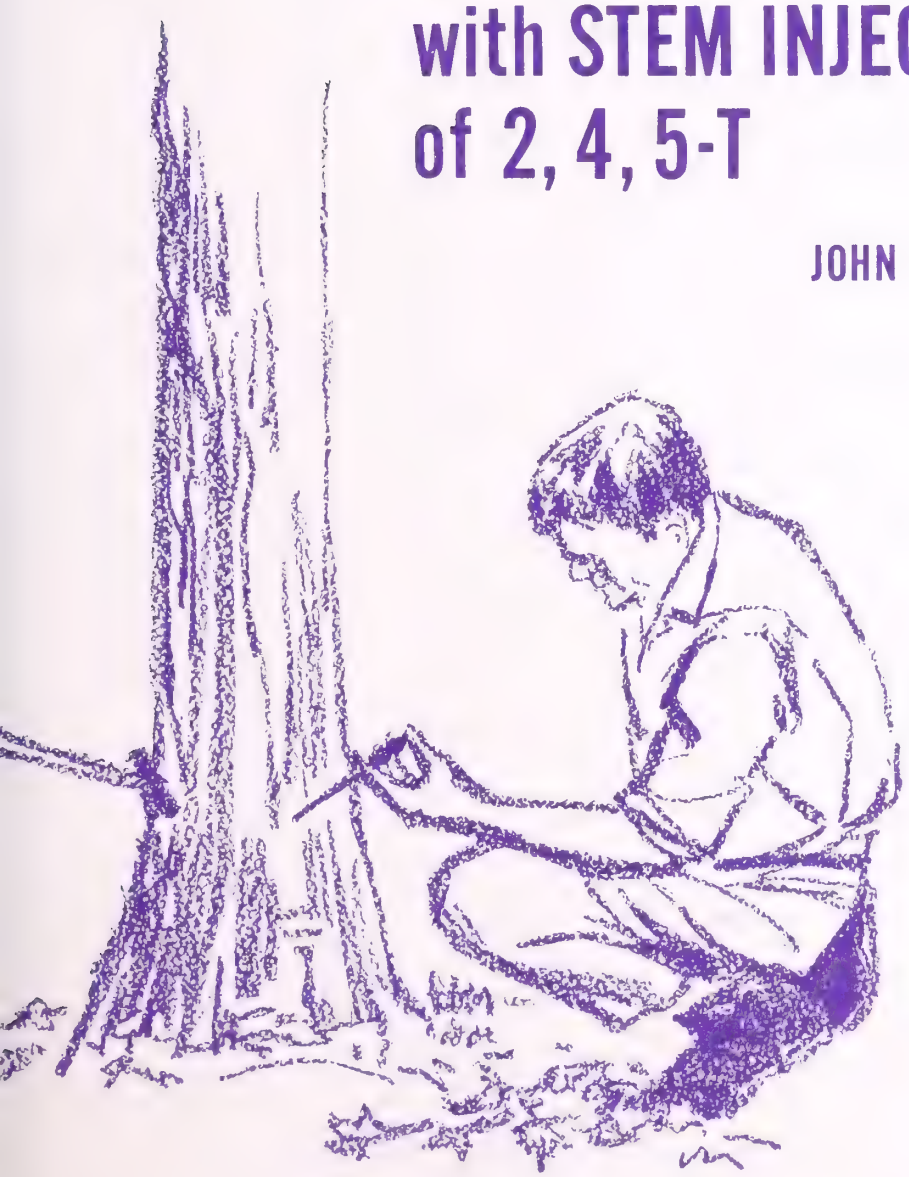
SOME VARIABLES AFFECTING HARDWOOD CONTROL with STEM INJECTIONS of 2, 4, 5-T

JOHN L. AREND



NORTH CENTRAL FOREST EXPERIMENT STATION
D. B. King, Director
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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NOTE: The author is Leader of the Silviculture of Mixed Hardwoods Project. He is headquartered at the Station's field office in East Lansing, Mich., which is maintained in cooperation with Michigan State University.

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Some Variables Affecting Hardwood Control With Stem Injections of 2,4,5-T

John L. Arend

To reduce the costs of killing weed hardwoods, many foresters use 2,4-D and 2,4,5-T in spaced stem injections rather than in edge-to-edge or overlapping cuts (complete frill girdles). The success of spaced stem injections depends, however, on many interacting variables. Some of the most apparent ones are the concentration or quantity of the herbicide formulations required per injection, spacing between injections, season of the year, and tree size and species. Just how and why these variables affect results has been little understood.

In 1962 comprehensive studies were started in Lower Michigan to learn how to use spaced stem injections to control low-quality mixed hardwoods at the least cost. The first study was designed to determine the effectiveness of a water-soluble amine salt of 2,4,5-T compared with an oil-soluble ester. The results demonstrate conclusively that the amine salt is better than the ester under all comparable conditions studied. However, its effectiveness varies greatly by season of the year and spacing between the injections. The damaged stem tissues found in trees killed and not killed by the treatments showed the general translocation that took place, which in turn helps explain the many variable results from tree injector studies and operations. This new information suggests new approaches for increasing the effectiveness of the stem injections and reducing costs in timber stand improvement operations.

The Study Area and Experimental Procedure

The study area was a 110-acre tract of mixed oak in Clinton County, Mich., near Lansing. The trees were about 65 years old and up to 80 feet tall; the stand was fairly dense — about 130 square feet of basal area per acre — and the tree crowns were crowded. The topography was nearly flat, and the soil was fine-textured and poorly drained. This combination of site features is very productive for oak.

Because of the many treatment variables to be compared, only one tree species, white oak (*Quercus alba* L.), was used for all combinations of the treatments. However, many of the treatments were also tried on other hardwoods to determine species resistance. The sample trees were single-stemmed and about 6 to 8 inches in diameter at breast height.

A complete randomized factorial design was used, with two herbicide formulations, five concentrations, four spacings, and three seasons combining into 120 treatments. Each treatment was replicated on five sample trees (total of 600) of similar size and vigor. The elements of the treatments were:

Herbicides: The triethylamine salt and the propylene glycol butyl ether ester of 2,4,5-T; both commercial formulations, 4-pound acid equivalent gallons.

Spacing between injections: 1, 2, 4, and 6 inches (edge to edge).

Concentrations of each formulation: 100 (undiluted), 50, 25, 10, and 5 percent by volume (acid equivalent per 100 gallons of carrier was 400, 200, 100, 40, and 20 pounds). The amine salt was diluted in water and the ester in No. 1 fuel oil.

Volume of herbicide per injection: 1 milliliter for 1- and 2-inch spacings, 2 milliliters for 4-inch spacings, and 3 milliliters for 6-inch spacings. These volumes were equivalent to about 1 milliliter per 3 inches of circumference or (roughly) per 1 inch of diameter.

Season of the year: Late dormancy, about 1 month before the buds started swelling (March 1962); peak of the growing season, about the time of full leaf development (mid-June 1962); and late growing season or early dormancy, about 1 month before leaf fall (late September or early October 1962).

An attempt was made to use an injection technique that would be accurate enough for experimental purposes and yet could be simulated with commercially manufactured tree injectors. A 2-inch-wide chisel was driven about ½ inch into the base of the tree with a short-handled sledge hammer. The herbicide was injected into each incision

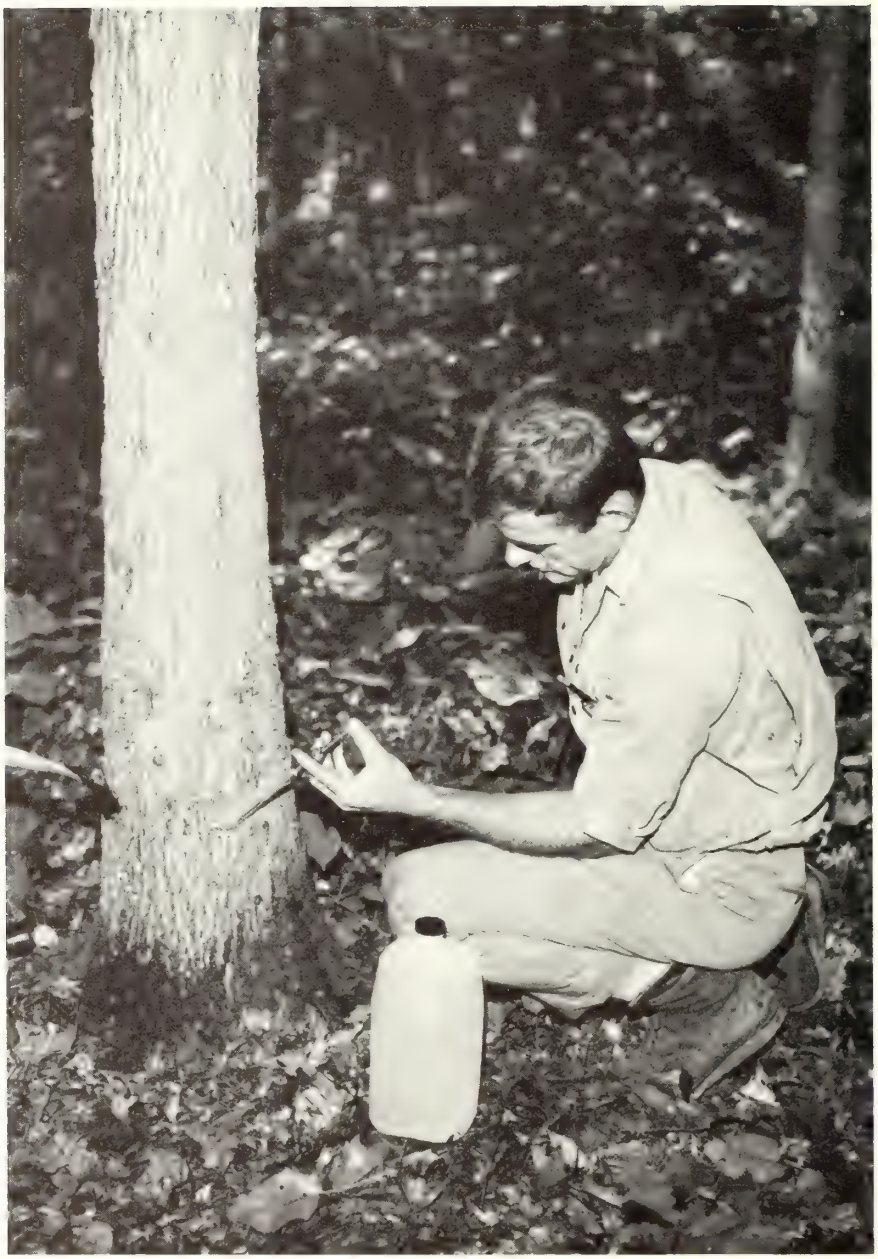

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FIGURE 1. — Injecting the herbicides with an automatic pipette into evenly spaced incisions made with a chisel.

with an automatic 2-milliliter pipette (fig. 1). This method gave reasonably consistent control over the width, depth, and spacing interval of the incisions and quantity of herbicide injected.

The injections were made 1 to 5 feet above the ground, depending on the presence of fire scars and other basal deformities. Our previous experience showed that herbicides injected into healed-over basal stem wounds were not effective. To test height effects further, several trees were injected about 20 feet above the ground (just below the crown) with the amine salt at 4-inch spacings.

The amount of apparent foliage damage or crown reduction on each tree was recorded annually to the nearest 10 percent for 3 years after the stem treatments. At the end of the third year, 81 treated but living trees (37 injected with the amine salt and 44 treated with the ester) and 80 killed trees were felled, and the stems were examined for killing effects in the conductive tissues.

Results

Crown Kill

After 3 years, analysis of variance showed all the major variables studied (herbicide formulation, concentration, spacing, and season of treatment) to be highly significant in terms of crown kill. Their effects on tree mortality were also important economically (table 1).

Amine salt versus the ester. — The amine salt killed 80 to 100 percent of the trees with concentrations diluted down to 25 percent at 1-inch spacing between the injections at all seasons. In June this concentration was equally effective at spacings up to 6 inches apart.

The maximum number of trees killed by the ester treatments was 60 percent. This was obtained with 1 milliliter of undiluted ester per injection for spacings 1 and 2 inches apart in March and 1 inch apart in June. The next best results, 40 percent of the trees killed, was obtained when the ester was diluted with oil to 50 percent by volume and injected at 1- and 2-inch spacings in March. Only an occasional tree was killed with lesser concentrations or at wider spacings.

The comparative results show that at least four times more ester than amine is required to kill oak at 1- and 2-inch spacings between injections in March. The ratio of ester to amine is much larger at wider spacings and at other seasons of the year.

Seasonal effects. — The ester of 2,4,5-T was most effective in March, less effective in June, and completely ineffective in October with the treatments tried (table 1). However, it killed too few trees for seasonal effects to be fully appraised. The amine salt was definitely most effective when stem-injected during the peak of the growing season. The June treatments killed three times as many trees as the March treatments and twice as many as the October ones. The salt is therefore at least twice as effective when injected during the growing season as during the dormant season.

Interrelations of concentrations and spacings. — The concentration or quantity of 2,4,5-T per injection had to be increased as the distance between spacings was increased in order to kill the trees. For example, during the dormant season the 6-inch spacing was ineffective with any of the quantities of 2,4,5-T amine used. However a few trees were killed with the same concentrations at 4-inch spacings, more at 2-inch spacings, and all trees at 1-inch spacing with concentrations of 50 percent and higher. During the growing season, the 25-percent concentration of the amine killed all trees when injected at all spacings up to 6 inches apart; but at 1-inch spacings concentrations as low as 10 percent killed all the trees.

Height of spaced injections. — This appeared to have little effect on top kill when placed above basal stem defects. In fact, trees treated by injections 3 to 5 feet above the ground seemed easier to kill than those treated near the root collar. The several trees stem-injected 20 feet above the ground just below the crown during the growing season were top killed in about 2 weeks.

Basal Sprouting

Less than 2 percent of the hardwoods top killed by the treatments (and none of those top killed by injections 20 feet above the ground) developed basal sprouts after 3 years. In fact, more treated trees that were not top killed developed basal sprouts than those showing top kill effects. In contrast, most hardwoods that were cut or completely frill girdled in this same tract without chemical treatment developed basal sprouts the first growing season. And in our 1954-55 treatments with 2,4-D and 2,4-5-T in complete frill girdles on red and white oak in this stand, about half the trees sprouted.

Species Resistance

White oak was selected initially as a test species in this particular study because we had some evidence that it might be more resistant to systemic herbicides than red or black oaks. Our 1954 results, using the amine salt and ester formulations of 2-,4-D and 2,4,5-T in complete frill girdles, showed white oak to be more difficult to kill, at least in April, then northern red oak. Then too,

TABLE 1. — *Percentage of white oaks killed 3 years after stem injections of 2,4,5-T amine and ester at different concentrations, volumes, spacings, and seasons of the year*[1]

Concentrations (percent)	Date treated					
	March 1962		June 1962		October 1962	
	Ester	Amine	Ester	Amine	Ester	Amine
	1 ML. PER 1-INCH SPACING					
100	60	80	60	100	0	100
50	40	100	0	100	0	100
25	0	80	0	100	0	80
10	0	20	0	100	0	60
5	0	60	0	60	0	60
	1 ML. PER 2-INCH SPACING					
100	60	60	0	100	0	100
50	40	40	0	100	0	100
25	0	40	20	100	0	60
10	0	0	0	60	0	0
5	0	0	0	40	0	0
	2 ML. PER 4-INCH SPACING					
100	0	0	0	80	0	40
50	0	20	0	100	0	0
25	20	20	20	100	0	0
10	0	0	0	60	0	0
5	0	0	0	40	0	0
	3 ML. PER 6-INCH SPACING					
100	0	0	0	100	0	40
50	0	0	0	100	0	0
25	0	0	20	100	0	0
10	0	0	0	60	0	0
5	0	0	0	20	0	0

1/ Four-pound acid equivalent gallons were used with both herbicides. The amine (triethylamine salt) was diluted with water, and the ester (propylene glycol butyl ether ester) with No. 1 fuel oil. Spacing was measured edge to edge of 2-inch cuts made ½ inch deep with a wood chisel. Each of the 120 treatments was applied to 5 trees. Trees completely defoliated in August 1965 were considered dead.

the xylem vessels of white oak are normally blocked by tyloses. However, these tyloses are most abundant in the older xylem being transformed to heartwood and are normally not found in the new sapwood where vertical translocation takes place.

In the spaced injection treatments, especially at lower concentrations and wider spacings, white oak was consistently killed more easily than northern red oak. Since both species were of similar diameter and growing side by side in the same stand, these results indicate that northern red oak might be more resistant to stem injections of 2,4,5-T than white oak. However, this resistance could be caused by tree characteristics other than species. The northern red oaks generally appeared more vigorous and many of them had larger crowns than white oak of the same stem diameter. Elm and ironwood (hophornbeam) were killed as easily as white oak, but hickory was difficult to kill.

What causes species resistance other than crown size and branching characteristics could not be determined. Perhaps it is anatomical differences. Wiant and Walker (1961) found that ring-porous species were more easily killed by complete mechanical stem girdles than diffuse-porous species. Our results showed that translocation was much slower in diffuse-porous species from spaced stem injections; at least top kill effects took longer to show up.

Killing Effects in Conductive Tissues

The killing effects observed in the conductive tissues of the stem from 2,4,5-T in this study and the apparent translocations that took place have been described in a previous paper (Arend 1967). The results are briefly reviewed here as background for the ensuing discussion.

The damage in the conductive tissues showed that the superior effectiveness of the amine salt over the ester was due, in part at least, to the increased vertical translocation above the injections to the crown and possibly to phloem translocation away from the foliage to other parts of the tree, including movement down the stem to kill the underlying cambium. The difference was not due to tangential movement between the injections in the xylem.

Too few trees were killed with the ester to assess its lethal effects; but evidence from the few killed trees and from those not killed by the treatments indicates that the ester is translocated in the same pattern as the amine but to a lesser extent with the same quantities.

Tangential movement. — The tangential killing effects in the sapwood caused by oil-diluted ester were similar to those caused by the water-diluted amine salt. In sound trees, the sapwood was killed tangentially for an average distance of only 0.2 inch on each side of the injections (fig. 2). Above the injections the killed portion of the sapwood gradually narrowed (fig. 3). The exception to this limited tangential movement was found in trees that had incipient stages of decay in the heartwood, with possible extensions into the sapwood. Under these conditions, both formulations of 2,4,5-T moved profusely in all directions, and presumably could kill trees by girdling them. This type of damage was found in several killed trees.

Radial movement. — The injected 2,4,5-T killed the sapwood radially inward from the bottom of the injections to various depths, but no deeper than the heartwood in normal trees. The most important lethal effects appeared to be obtained by radial movement between the xylem and the phloem; both of these vital tissues including the cambium were seriously damaged. The inner bark and cambium above and below the injections were killed as far up and down the stem as the underlying damage found in the xylem. This was especially noticeable in trees not killed by the treatments (figs. 2 and 3). Stout and Hoaglund (1939) also found radial movement between the xylem and the phloem with radioactive isotopes of potassium, sodium, and phosphorus when they were absorbed by the roots.

Vertical movement above the injections. — Streaks of dead conductive tissue (both xylem and phloem) extended to various heights along the stem above the injections, depending on the 2,4-5-T formulation, its concentration, the quantity applied, and season of the year (fig. 3). For example, where it could be measured in unkilled trees, the amine salt killed the sapwood, cambium, and inner bark above the injections two to four times higher up the stem than the ester at the same concentrations. The amine salt injections made during the peak of the growing season also killed the conductive tissues twice as high up the stem as the dormant-season applications.

In trees showing complete crown kill 3 years after the treatments, the dead sapwood channels above the injections could generally be traced to the base of several main branches. The most important difference found in the stems of killed versus unkilled trees was a narrow band of killed sapwood in the upper portion of the stem. This band decreased in radial depth downward from the top and usually disappeared above the injections (fig. 4), its length varying with the quantity of amine injected. This killing effect in the sapwood appeared to result from radial movement of the herbicide from the phloem as it was carried down the stem from the foliage.

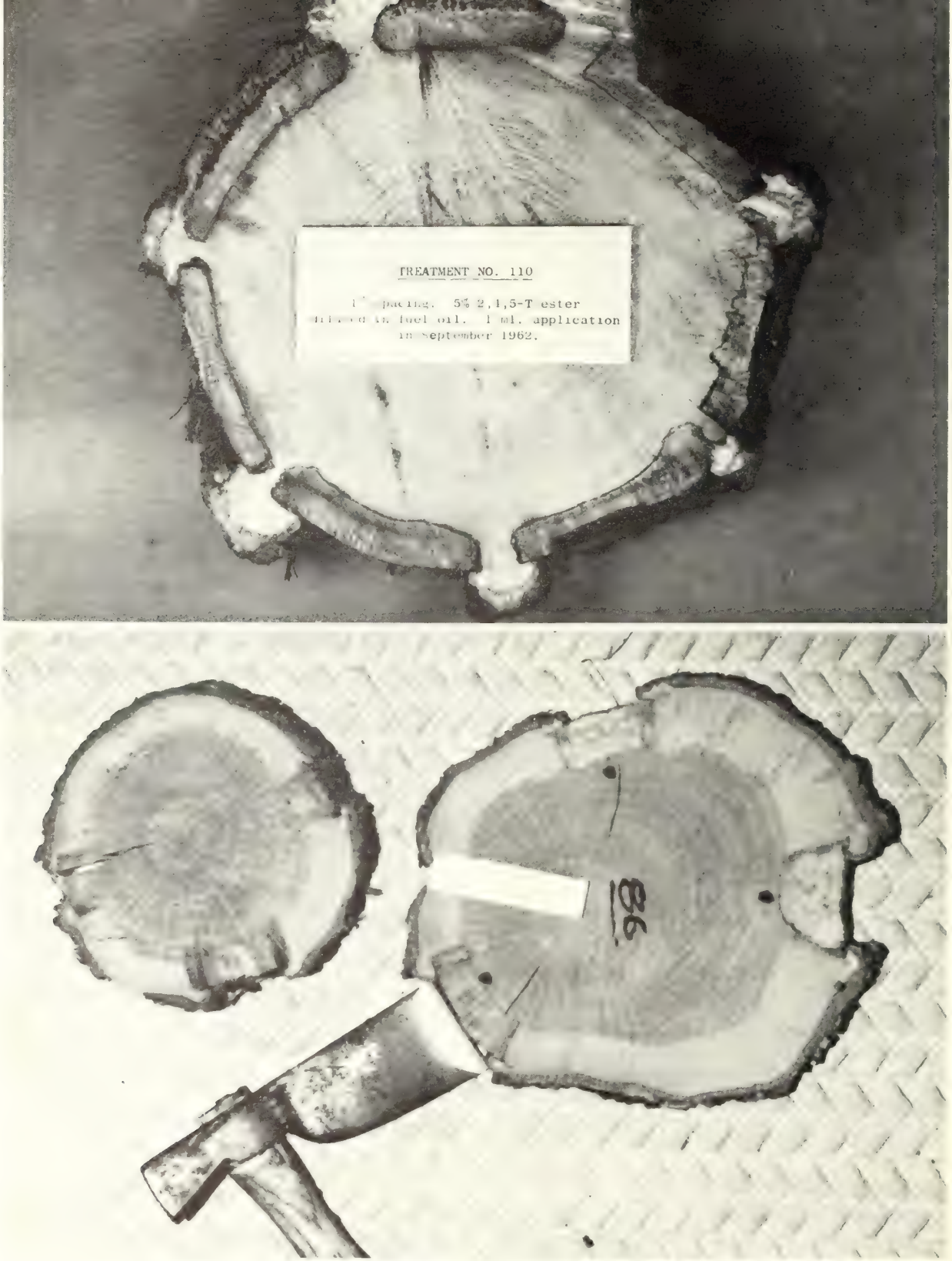

FIGURE 2. — Cross sections of the stems of unkilled white oak showing the limited tangential movement of injected 2,4,5-T, 3 years after treatment. *Upper photo*: 1 milliliter of 5-percent concentration by volume of 2,4,5-T ester diluted in fuel oil. Spacing between the injections was 1 inch (edge to edge). *Lower photo*: 3 milliliters of 25-percent concentration by volume of 2,4,5-T ester diluted in fuel oil. Spacing between the injections was 6 inches (edge to edge). Smaller cross section was taken halfway up the stem, the larger cross section at the site of the injections. F-516604 & 605

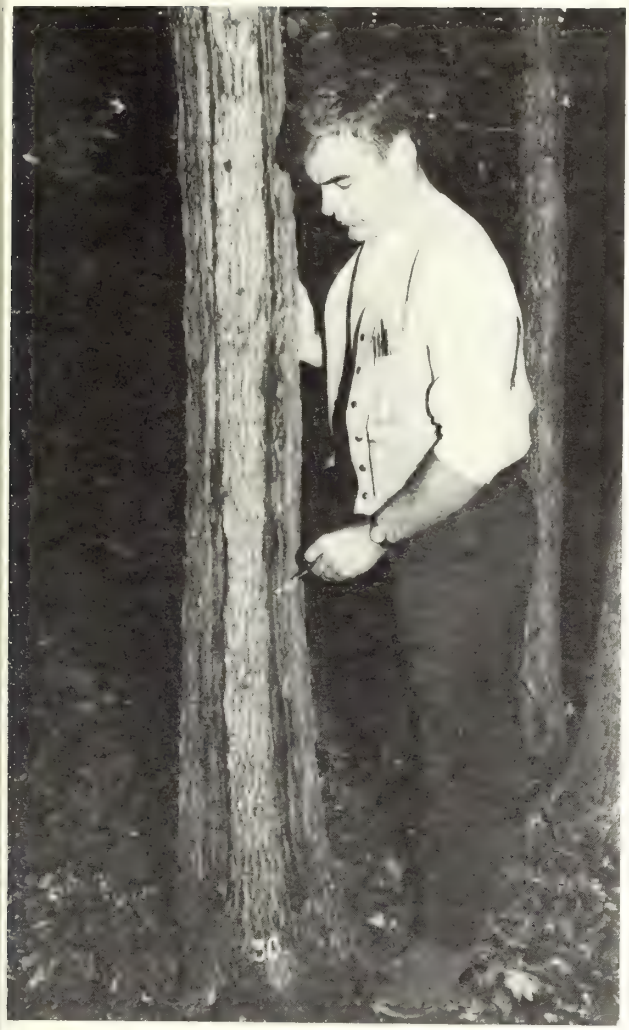

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FIGURE 3. — Narrow streaks of killed sapwood, cambium, and phloem above the injections in unkilled white oak trees. Treatment was 2 milliliters of undiluted 2,4,5-T amine injected at 6-inch spacings (edge to edge).

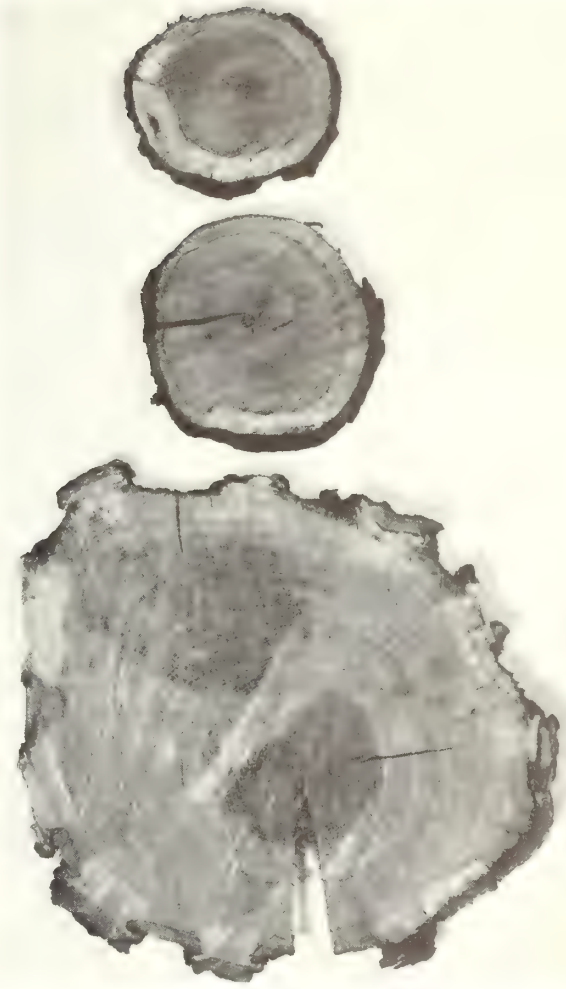

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FIGURE 4. — Cross sections of the trunk of a killed white oak injected with 1 milliliter of 2,4,5-T amine at 1-inch spacings in March 1962. The bottom section, site of the injections, shows no apparent damage to the tissue between the injections. The top section taken at a height of 50 feet, immediately below the crown, shows a wide band of dead sapwood. The middle section, taken at a height of 40 feet, shows a narrower band of dead sapwood.

Vertical movement below the injections. — The xylem and phloem below the injections were killed for distances of about 6 inches to 3 feet — again in narrow paths about the width of the injections. Although this killing effect added to the total stem damage, its contribution to tree mortality was apparently unimportant. Its extent appeared to be influenced somewhat by the same variables affecting upward movement above the injections. The downward movement below the injections could have taken place in both the xylem and the phloem. The reverse xylem flow at this point, according to Sudia and Linck (1963) and Zimmerman,[1] could have resulted from the tension in the water column of the xylem being broken by the injection, permitting movement in both vertical directions until an equilibrium was established.

[1] *Personal conversation with Dr. Martin H. Zimmerman, Harvard Forest, Petersham, Massachusetts.*

Discussion

The superior crown kill results of the water-soluble amine salt compared with the oil-soluble ester formulations of 2,4,5-T obtained in this comprehensive study are similar to those reported by many investigators from more limited tests: Westing (1955) in Michigan, Leonard (1956) in California, Gibbs (1959) in Texas, Peevy (1962) in Louisiana, Starr (1963) in Mississippi, Benzie and Ringold (1964) in Minnesota, and others. Many of them also found that 2,4-D amine is at least as effective in basal stem injections as 2,4,5-T amine.[2] It is also about one-third less expensive. However, we used 2,4-5-T in both formulations in this study in order to specifically compare a water-soluble amine salt with an oil-soluble ester of the same basic acid under nearly identical conditions.

The results conclusively demonstrate the superiority of the water-soluble amine salt over the oil-soluble ester in basal injections. In addition, the damage found in the conductive tissues from the different injection treatments, especially the amine salt, and the effects of height of the stem injections on tree kill are new information that helps to explain many previously unexplainable results.

Apparently smaller quantities of the amine salt (one-fourth or less) killed more trees than the ester mainly because of more extensive translocation up the stem to the crown and then away from the foliage by way of the phloem, the latter movement permitting extensive damage to the cambium and roots. Such translocation explains how trees are killed not only by spaced stem injections but also by complete frill girdles. And it also helps explain the role of major variables, such as concentrations, spacings between injections, and tree size, and their interrelationships.

With complete stem girdles, the phloem is entirely severed and the sapwood is cut to various depths. This mechanical injury alone stops translocation of foodstuffs through the phloem to the roots. If the sapwood is also completely severed, water movement from the roots to the leaves is cut off and the tree crown is killed, mainly from desiccation. The addition of certain chemicals like 2,4,5-T will help to kill the tree. The 2,4,5-T will move upward, and slightly downward — the extent of its vertical movement depending on its formulation, concentration or quantity applied, and season of the year. If sufficient herbicide is applied, it will reach the foliage and hasten top kill. Downward movement below the complete girdle is affected by the same variables, but with most herbicides it is limited. This explains the early observation that low frills and higher concentrations of 2,4,5-T will reduce sprouting (Arend 1953). There is virtually no tangential movement in the xylem which explains why with small quantities of diluted 2,4,5-T, the frill girdle must be complete (Carnes and Walker 1956). Adding a diluted 2,4,5-T solution to complete frill girdles reduces costs because the girdle can be shallow since the chemical will move in toward the heartwood to kill the remaining unsevered active xylem. The diluted 2,4-5-T will also hasten top kill, reduce basal sprouting, and prevent the shallow frill girdle from healing over.

With spaced stem injections, both the phloem and the active xylem are only partially severed. The herbicide needs to translocate to more than half of the crown and preferably from the foliage to the roots via the phloem to reduce and even prevent basal sprouting. Trees top killed by this method seldom sprout. Generally less labor is required to make spaced injections than complete frill girdles, but because of the extensive translocation needed to kill the tree, larger quantities of the herbicide are required, the amount depending on many variables.

The complete chemical frill girdle method will always have application for the selective control of weed trees, especially large ones that are difficult to kill by spaced stem injections. Costs can be reduced by knowing which method to use on a specific weed tree.

Quantity of 2,4,5-T required per injection. — The 2,4,5-T must be applied in sufficient quantity to reach the crown. Otherwise, only narrow streaks of sapwood and the overlying cambium and inner bark (phloem) about the width of the injections will be killed to various heights along the stem (fig. 3). Northern oaks are quite resistant to this type of damage. We have oaks still living 5 years after being damaged by unsuccessful stem injections of 2,4-5-T spaced 1 inch apart.

The first herbicide requirement discovered for spaced stem injections using 2,4-5-T ester diluted in oil was that higher concentrations were needed (Smith 1959). This was also true for ammonium sulfamate (ammate); this systemic herbicide, when applied in supersaturated water solutions, was effective in complete frill girdles but not in spaced injections. There, it had to be applied in concentrated crystalline salt form to basal stem cups spaced about 4 inches apart in order to kill the tree, an illustration of the higher concentration requirement of herbicides for use in spaced injection treatments (Peevy 1949).

[2] *Red maple* (Acer rubrum L.), *however, is more susceptible to 2,4,5-T amine stem injections than to 2,4-D amine,* (*Day, 1960*).

Many other variables also influence the quantity of 2,4,5-T required per injection and per tree. Tree size determines the vertical distance the herbicide must translocate to reach the crown and the amount of foliage that must be reached. Anatomical differences among species, individual crown characteristics, and conditions affecting transpiration could affect the lethal quantity of 2,4.5-T per injection.

Spacing interval required between the injections. — The injections need to be spaced around the stem to permit the herbicide to reach a majority of the crown. Postlewait and Rogers (1958) found that radioactive isotopes of phosphorus-32 and iodine-131 injected into the stems of shagbark hickory, red pine, and blue beech moved up the trunk in the xylem in narrow paths and passed into the branches most closely associated with that section of the transpiration stream. Therefore, the number of injections around the tree and their width (total circumference injected) determines the amount of foliage affected. However, uniform distribution of the injections around the stem is more essential than the proportion of the stem injected. Watson and Mesler (1964) found that frill girdling one-half of the circumference and adding Tordon was ineffective on pole-size and larger oaks whereas equally spaced injections that severed 50 percent of the circumference killed the same size trees.

Many results also show that trees — especially the smaller ones — can be killed by severing less than 50 percent of the circumference with stem-injected herbicides. The criterion appears to be the proportion of the crown reached by the herbicide. Our study showed that if 60 percent or more of the crown exhibited some effects of the herbicide injections within 1 to 2 full growing seasons after the treatment, the tree would die. Character of the branching off the main stem as well as crown size affect the spacing required between injections. One injection of systemic herbicide may kill a small sapling because a major portion of the crown is reached. But trees with large spreading crowns — especially those with low, large branches or forked stems — require closely spaced injections as well as large quantities of herbicide per injection to kill them.

Effects of tree size. — Generally as trees increase in size, larger quantities of 2,4,5-T per injection and closer spacing of the injections are required. The effects of tree size persist even though, with the same spacing and quantity of herbicide per injection, the total volume of herbicide received per tree is directly proportional to the diameter of the stem — i.e., as the stem diameter doubles the volume of herbicide per tree will also double. This constant increase of herbicide per tree with increasing stem diameter appears to be effective for trees up to small sawtimber size; but larger quantities per injection and closer spacing are generally required to kill large sawtimber trees. Apparently the crowns of larger trees increase greatly in size with larger stem diameters.

The fixation loss characteristic of the phenoxy herbicides as they move through the conductive tissues may be another reason why more 2,4,5-T is required as the tree increases in size.

Height of spaced stem injections. — Trees in this study were killed by spaced stem injections at any height above the ground, including some just below the crown. Probably the higher the injection, the more herbicide translocated to the foliage. Generally about 20 percent fewer injections are required at breast height compared to stump height at the same effective spacing. This reduced number of injections not only reduces the herbicide used, but it speeds up the work and increases the number of trees that can be treated per day. This information provides incentive for developing tools to make injections higher on the stem than is convenient with most tree injectors now available. One such tool meeting this requirement is a hypo-hatchet.[3]

Why seasonal effects? — This study and most others show that hardwoods can be killed with a smaller quantity of 2,4,5-T amine applied at wider spacings between injections during the peak of the growing season than during the dormant season. This effect can result in a substantial difference in costs; and specific prescription rates should be worked out for each forest region based on stages of growth.

The possible reasons for the seasonal differences in effectiveness of the phenoxy herbicides include the following: First, during the growing season transpiration is rapid, the injected herbicides move quickly in the transpiration stream to the foliage, and there is less opportunity for fixation losses along the translocation route. In contrast, injections in the dormant season remain near the injection sites or at most move up the stem slowly until the foliage develops (Witherspoon 1964). Consequently more dormant-season-injected 2,4,5-T can be absorbed and fixed in the xylem, and less is available when it moves to the foliage in the spring. Secondly, the new tree tissues developing during the peak of the growing season may be more susceptible to 2,4,5-T. Overbeek (1947) found that 2,4-D was most active against cells in the meristematic state.

A few cases have been reported where 2,4,5-T amine injected during the growing season was in-

[3] *Several types of hypo-hatchets are now being manufactured.*

effective in controlling hardwoods. We found one instance in northern Michigan where injected 2,4,5-T amine defoliated red maple within a few days, but the trees leafed out the next year without showing further damage to the trees. In the Southeast, McGee (1966) reported that 1-milliliter quantities of 2,4,5-T amine injected in April when the leaves were just developing caused them to fall and the treatments were less effective than July treatments. Apparently, under certain early season growing conditions too large dosages of stem-injected 2,4,5-T amine can cause the leaves to fall off without killing the tree.

Another seasonal effect possible with spaced stem injections is reduced tree kill when soil moisture is critical during the mid- or late growing season. Merkle and Davis (1967) found that 2,4,5-T did not move readily in the phloem of beans under low moisture stresses. This could explain the poor tree kill from foliage sprays and spaced injections of 2,4,5-T that has occurred during the periods of critical soil moisture common in many forest regions during the growing season.

Conclusions

1. A triethylamine salt of 2,4,5-T was at least four times more effective in spaced stem injections on northern oak than a propylene glycol butyl ether ester of 2,4,5-T. Not only were smaller quantities of the amine salt required per injection, but wider spacings between the injections were possible.

2. About one-half the quantity of amine per injection was required during the growing season compared to the dormant season to kill pole-size oak. With the same quantity of amine per injection, pole-size oak could be killed with spacings of 6 inches (edge to edge) between the injections during the growing season compared to about 2 inches during the dormant season.

3. Height of the spaced injections on the stem had no apparent effect on tree kill if placed above basal deformities and below the crown. Oaks were most easily killed by spaced stem injections just below the crown. However, because of the limited downward movement of 2,4,5-T below the injections, complete edge-to-edge injections and complete chemical frill girdles which entirely sever the phloem should be placed close to the root collar to reduce basal sprouting.

4. Trees top-killed by spaced stem injections with 2,4,5-T seldom develop basal sprouts regardless of the height of injections on the stem.

5. Studies of stem damage indicated that the superior effectiveness of the amine salt compared to equal quantities of the ester resulted from more extensive translocation in the conductive tissues.

6. The tangential killing effects in the xylem were not important. Also no difference was found between the amine salt and the ester, including the dilutions in water and No. 1 fuel oil.

7. The quantity of 2,4,5-T required per injection appears to depend on its formulation, season of the year treated, spacing between the injections, and tree size, particularly the size and character of the crown. The spacing distance between the injections also appears to depend on the same variables.

8. Trees with large spreading crowns and forked stems are difficult to kill by spaced stem injections with 2,4,5-T.

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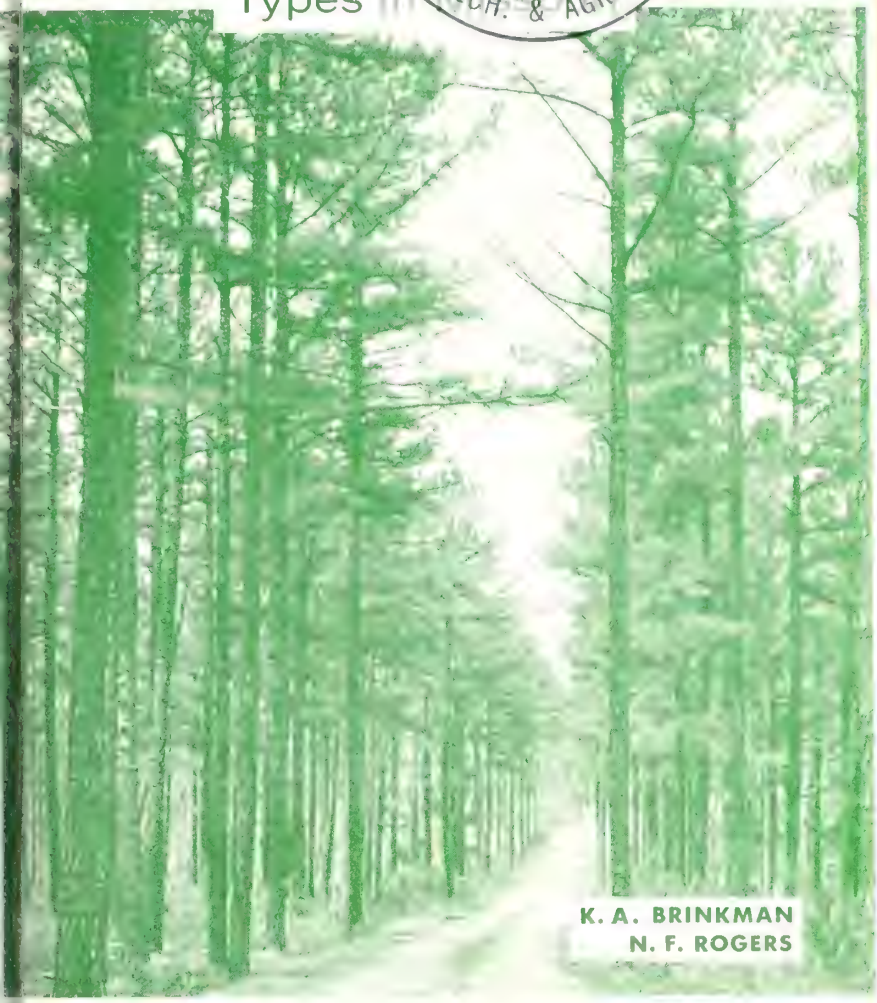
Timber Management Guide for Shortleaf Pine and Oak-Pine Types in [illegible]



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Timber Management Guide for Shortleaf Pine and Oak-Pine Types in Missouri

K. A. Brinkman and N. F. Rogers

The management practices recommended here for the shortleaf pine and oak-pine types in Missouri are based on published information, research in progress, and the knowledge and experience of forest managers. The suggested practices should not, however, be interpreted as the final word in management — modifications will be necesary as forest researchers and managers learn more about the silviculture of these types. Furthermore, no set of rules can replace the need for technical knowledge and judgment by the forest manager. But the guides do provide a basis for decision making, and their use will improve continuity in the management of these important forest types.

Alternatives of management are not discussed. The decision to favor pine or oak-pine stands over hardwood stands must be made on the basis of the objectives of the landowner and within the limitations of site productivity.

Pine Range and Type Descriptions

Shortleaf pine, the only pine species growing naturally in Missouri, is found within a gross area of 6 million acres in the State. The natural stands are in the southern part, most of them in the southeast. Beginning in the middle 1930's, the species' range was extended by plantings over much of Missouri. Many trees in these plantations have already grown to merchantable size.

Shortleaf pine is usually found growing with oaks and other hardwoods. Nearly pure stands of pine may develop after a fire or as a result of intensive management, but the ecological trend is toward stands containing more hardwood trees. Thus the pine component of stands may vary widely within the species' natural range. For convenience, two forest types are commonly recognized.

The shortleaf pine type consists of stands in which pine comprises 50 percent or more of the cubic volume in sawlog or poletimber stands, or of the total number of trees in seedling or sapling stands.

In the oak-pine type, hardwoods (usually upland oaks) make up 50 percent or more of the cubic volume in large trees or of the number of smaller trees, with shortleaf pine providing from 25 to 49 percent of the stand.

The above type descriptions are the ones used in Forest Survey reports. Like any type descriptions they are somewhat arbitrary. Some foresters may prefer to use basal area instead of cubic volume as a basis for judging the type.

Cutting relatively few trees in some stands would, of course, change the type designation.

Soils

Except for colluvial slopes and alluvial bottom lands the soils of the Ozark Highlands are residual in origin. A thin layer of loess, deposited during glacial periods, has nearly all been eroded away, and weathering and erosion of the underlying rocks have left a mantle of insoluble chert over most of the area.

The chert content of stony soils may vary from a few fragments to 75 percent by volume of the soil mass to a depth of about 5 feet. In more than one-half of the soil types 30 percent or more of the soil is chert; it may be most abundant in the surface (A) horizon or distributed evenly throughout the soil profile. A high content

nert in the soil profile or the presence of a fragipan seriously affects the soil moisture regime, causing soils to e drouthy. These drouthy conditions are more pronounced on ridgetops, upper slopes, and south and west spects.

The shortleaf pine type usually occurs naturally on oils characterized by dryness. Soils series generally classified as gravelly or stony loams, being low in clay content and relatively low in fertility, include Bodine, Clarksville, Christian, and Coulstone. The Dickson, Hobson, ebanon, and Nixa soils have definite fragipans.

Oak-pine stands are better suited to soils developed om dolomitic parent materials rather than cherty limeones. These soils contain considerably less chert, lack ell-developed fragipans, are weathered deeper, and rovide a better moisture supply than soils on typical ne sites. The principal soil series are: Baxter, Dewey, ullerton, Minvale, and Talbott.

Sites

Shortleaf pine trees are not always present on sites here the forest manager suspects that pine would grow ell. But black oak trees 40 to 60 years old occur on wide variety of sites; therefore, it is convenient to iscuss site quality for both pine and oak in terms of lack oak site index. (Site index usually is expressed as he height that dominant trees will attain in 50 years.)

Although shortleaf pine occurs naturally where the lack oak site index may vary from 30 to 80, commercial roduction of pine may not be profitable on all these tes. In general, where the site index is 45 or less, rowth rates usually are too low to warrant intensive anagement of either oaks or pine, and where site index xceeds 65, oaks and other hardwoods grow fast enough o overtop pine trees unless they are released periodicalr. So pine or oak-pine stands usually will be managed here the site index ranges from 50 to 65.

In unmanaged stands the shortleaf pine type is usually limited to narrow ridgetops and the upper slopes with south and west exposures. On these drouthy sites pines predominate because they tolerate the inadequate moisture supply better than most other desirable species. Where the pine type occurs naturally, site index usually is 50 or less, but pine stands can be grown on much better sites.

The more extensive oak-pine type occurs on north and east exposures and on middle and lower slopes of south and west exposures where moisture is more abundant. Site index usually ranges from 50 to 65. Where the oaks are of poorer quality, pine should be favored.

In the oak-pine type where the site index exceeds 65, periodic release of the pines from the fast-growing hardwoods may be profitable only where good pine markets exist.

Silvical Characteristics of Shortleaf Pine

Tolerance

Although older shortleaf pine trees are intolerant to shade, suppressed seedling and sapling pines in the understory respond well to release up to age 25 if they are not too badly deformed.

Seed Production

Good seed crops usually occur at intervals of 5 to 7 years. Some seed is produced nearly every year by full-crowned dominant trees, and some trees consistently bear seed. Heavy thinnings, leaving 30 to 50 square feet of basal area per acre in stands over 30 years old, will result in larger tree crowns and increased seed production.

egeneration

Where an adequate seed source is present, obtaining atural pine regeneration on prepared sites is not diffi- ult. At least 5, preferably 10, well-distributed good seed rees per acre are required.

Thinned stands sometimes have abundant pine re- roduction, but a dense hardwood understory or a heavy ardwood leaf litter often precludes successful pine stablishment. Such sites can be prepared by killing the nwanted hardwoods with herbicides and then, in the te summer or early fall of a good pine seed year, mak- g a prescribed burn. Where there are too few pine seed rees, direct seeding (or planting) can be used. On rocky tes where machine planting is impossible, direct seeding osts much less than hand planting and usually will be qually successful. Because good pine seed crops are pro- uced infrequently, the time required to establish natural egeneration will be reduced by direct seeding.

rowth

Where site index is 55 to 60, pine trees will attain eights of 35 to 40 feet by age 25 (fig. 1). Height growth ate averages a foot a year between ages 25 and 40, 0.8 oot from age 41 to 60, and 0.5 foot in older stands. These rowth rates are similar to those for black oak and scarlet ak to age 40, but older oak trees maintain rapid height rowth somewhat longer than pines, especially where oak ite index exceeds 65.

Diameter growth rates of individual trees are direct- y proportional to crown size. For maximum growth, rown length should be at least one-third of total tree eight. Where good crowns are maintained on trees by eriodic thinnings in post-size or larger stands, average .b.h. growth rate is about 2 inches with every 10-foot ncrease in total height. Both diameter and height growth ates decrease with tree age and size, but good merchant-

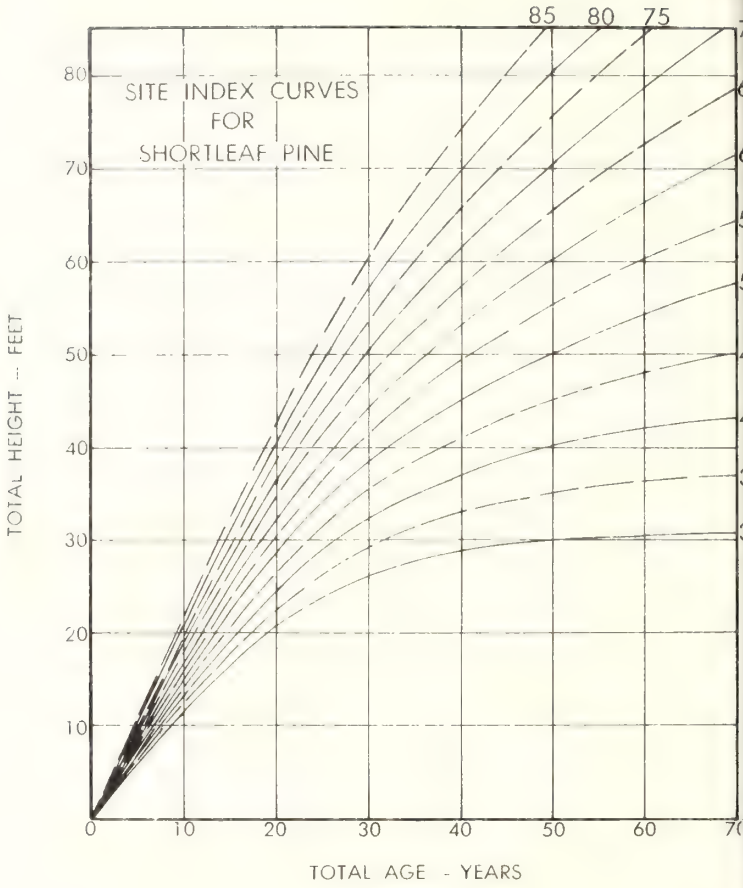

Figure 1. — Site index curves for shortleaf pine in M souri. From A. J. Nash, "A method of classifying sho leaf pine sites in Missouri," Missouri Agr. Exp. Sta. Re Bull. 824; 1963.

ble volume growth rate of larger trees is maintained for many years.

Susceptibility to Damage

Fire. — Tops of pines in the seedling and sapling size classes may be killed by light fires. Because thrifty trees as large as 3 inches d.b.h. usually sprout vigorously, the major effect of fire on such trees is loss of growth rather than mortality. However, multiple-stemmed trees result where several sprouts persist.

Fire damage to larger trees usually is limited to butt scars caused by heavy fuels burning near the base of trees; these scars usually pitch over and thereby prevent entrance of decay fungi.

Crown fires are rare in the shortleaf pine type; but when they do occur, both pole and sawlog-size trees may be killed.

Insects. — Larvae of Nantucket tipmoth, red-headed pine sawfly, and loblolly pine sawfly injure the growing tips and eat the foliage of pine trees. Tipmoth populations may be locally destructive for several years before natural predators control the insects. Damage is most severe in plantations outside the natural pine range. No practical direct control method is known.

Turpentine and engraver beetles may kill healthy as well as weakened trees after nearby stands have been logged. Valuable trees, as in seed production areas, can be protected by spraying the lower trunks of the trees with a 0.5-percent solution of benzene hexachloride in fuel oil.

Disease. — The greatest threat to pines is *Fomes annosus,* a root rot that is most common in planted old-field stands. It also occurs in natural stands, but there the rate of spread is much lower and no treatments are needed. Once the disease is established on old-field sites,

however, it is persistent. Dusting fresh-cut stumps with powdered Borateem[1] or applying a 10-percent Borateem-water solution prevents establishment of the fungus. This must be done immediately after trees are cut. To further reduce opportunity for infection on old-field sites, the number of thinnings should be limited.

The round galls caused by *Cronartium cerebrum* are found on many trees, but they seldom damage the main stem except on badly suppressed young trees. Heavily infected trees should be removed in first thinnings and seed should not be collected from such trees.

Basic Management Guidelines

The objective of timber management is to achieve the highest economic returns the site can produce in the shortest period of time. Returns are commonly measured in dollars, but other, less tangible values may be involved. To meet the various multiple-use objectives on National Forests, some reduction in expected dollar values may be justified. Regardless of the specific management objective in the pine or oak-pine types, the following general guidelines apply:

1. Manage both types as even-aged stands; avoid creating two-storied stands. Do not cut potential oak crop trees to release pine seedlings or saplings unless (1) the oaks compete directly with a better tree in the main stand; or (2) you are harvesting the main stand. Because white oaks take longer to reach sawlog size than pines and the other desirable oaks, manage white oak in even-aged groups of trees where these occur on good sites.

2. As early as feasible in the rotation, select and favor potential crop trees on the basis of species, tree quality and vigor, and site index. Plan to increase the

[1] *The mention of this product does not constitute its endorsement by the U.S. Department of Agriculture.*

proportion of pine in young oak-pine stands where site index is 45 to 55 by eliminating inferior-quality hardwoods through commercial sale and TSI (timber stand improvement) operations. Where site index is 55 to 65, save more oak crop trees and manage as the oak-pine type.

3. Control the density and composition of growing stock through periodic intermediate cuttings to produce maximum volume and value returns during the rotation. Beginning about age 20 to 25, commercial thinnings may be made in pine stands and in the pine component of oak-pine stands. The poor market for small hardwoods usually means that these trees cannot be sold at a profit. Kill unwanted trees with herbicide to favor potential crop trees.

4. Select a rotation length in keeping with site potential, species composition, and management objectives. Rotation ages of most major species are similar. For intensively managed pine and oak-pine stands, the economic rotation usually will be 70 years or less, but an 80-year rotation often will be used on National Forests. And on good sites supporting stands of high-quality trees, the rotation may be as long as 90 years if the expected net returns for large trees are great enough to offset the additional costs for the longer rotation. In contrast, where the site index is 45 to 50, a post-pole rotation should be planned. Short rotations may be most profitable even on better sites, especially for plantations.

5. Provide for adequate regeneration of preferred species when mature stands are harvested or when converting hardwood stands to pine or oak-pine. Site preparation, direct seeding, planting, or other cultural measures should be applied where needed. In general, pine should be favored over oak species where the site index is 45 to 55. Release established pine regeneration in subsequent timber sales and by TSI.

Pine and Oak-Pine Stands on Forest Sites

Seedling and sapling stands. — If pine reproduction is adequate, remove any overstory hardwoods or pines by commercial sale or TSI. Where needed to complete pine regeneration, retain four to six good seed trees per acre, or direct-seed the openings to pine. Prepare the site as necessary. Thin or clean sapling stands to release potential crop trees spaced at least 10 to 12 feet apart; provide about 3 feet of crown growing space on two or three sides of such trees.

Pole stands. — Harvest or kill any old residual trees to leave an even-aged stand. Thin pine stands when the trees reach post size to leave about 65 square feet of basal area per acre. Increase "leave" basal area to 80 (trees 5-inch class and larger) at age 40. Provide about 4 feet of crown growing space on two or three sides of each potential crop tree.

The oaks have wider crowns than pines of the same d.b.h., so leave from 5 to 10 square feet less basal area after thinnings in the oak-pine than in the pine type. Thus the basal area to leave will be adjusted for stand composition.

The basal area stockings shown here and elsewhere in the guide apply to uniform stands. Be sure to thin any clumps of trees to the prescribed level even though this may result in less than prescribed average basal area per acre. The main objective is to provide adequate growing space for crop trees.

Sawlog stands. — Desirable stocking level is 80 to 90 square feet of basal area per acre for uniformly stocked pine sawlog stands and somewhat less for oak-pine stands. Most trees this large show little response to release, but

hinnings will provide adequate crown space to maintain ood volume growth. Harvest excess merchantable trees, specially hardwoods and the poorer quality pines. Kill nmerchantable hardwoods with herbicides.

Regeneration stage — Where pine regeneration is nadequate when the stand reaches maturity, make a eed-tree cutting about 10 years before the final harvest ut. On pine sites, reduce stocking to leave about 40 quare feet of basal area in pine. Prepare the site for egeneration by killing unwanted understory hardwoods ith herbicides. If necessary, prescribe burn in the fall ust before a good seed crop matures. When at least 300 ell-distributed pine seedlings per acre are established, arvest the pine seed trees. An alternative procedure is o clear cut the mature stand, prepare the site as above, nd direct-seed to pine.

On oak-pine sites, somewhat more finesse is required o obtain the desired species mixture. Increase pine re-eneration as needed and kill unwanted species or in-ividual poor-quality oaks with herbicides. If the hard-oods are merely cut, their vigorous sprouts soon over-op adjacent pine seedlings.

ine Plantations on Old-Field Sites

Pole stands. — Because of the greater hazard of *omes annosus* infection, delay the first thinning until ge 30-35. Leave about 65 square feet of basal area per cre and *treat stumps*. The second and last thinning hould be made about age 50; leave 80 square feet of asal area.

Harvest cutting. — Economic rotation for most plan-ations is about 65 years when most trees can be sold or large poles or sawlogs.

If root rot (*Fomes annosus*) has not become estab-shed in the stand and growth has been satisfactory, plan o regenerate the stand. Leave about 25 seed trees per

acre; control excess hardwoods with herbicide; and prescribe-burn if necessary prior to seed fall. Harvest the rest of the trees as soon as adequate regeneration is obtained. An alternate procedure is to harvest the entire stand, prepare the site, and direct-seed. Always treat stumps of cut trees.

Examples of Recommended Treatments

Shortleaf Pine Sites

Stand Description	*Prescription*
Well-stocked pine stands more than 70 years old. Understory includes at least 300 well-distributed pine seedlings or 150 saplings per acre.	Unless expected future value justifies holding stand longer, harvest or kill all trees except pine regeneration. Control excess small hardwoods in understory with herbicides.
Stands as above but with inadequate pine reproduction.	Reduce stocking to leave 40 to 5 square feet basal area of pine pe acre. Prepare site for regeneratio by killing excess understory harc woods with herbicides. If neces sary, also prescribe-burn litte just prior to fall of good pine see crop. Harvest pine seed-trees afte regeneration is established. Alter nate procedure is to harvest a trees, prepare site, and direct-see or plant.
Pole stands (30 to 45 years old) or immature sawtimber stands with more than 70 square feet basal area of pine per acre.	Favoring pine where possible, r duce basal area of crop trees 1 70 to 85 square feet; amount wi vary with age and size of tree Leave potential hardwood cr trees not competing with pine Harvest or kill all other trees main stand.

ole or immature saw-mber stands with 50) 70 square feet basal rea of pine or hard-ood crop trees per ere.	Leave any potential hardwood crop trees not competing with pines; thin dense clumps of pine to leave 70 to 80 square feet basal area (hardwood crop trees and pine) per acre. Sell or kill other trees of any species. Convert stand to pine type at maturity.
ole or immature saw-mber stands over-ocked with inferior ardwoods and with ss than 50 square feet asal area of pine or ardwood crop trees er acre.	These problem stands often are not worth managing to maturity. Either (1) provide growing space for pine and oak crop trees by removing competing inferior-quality hardwoods, or (2) convert stand to pine by direct-seeding.
Vell-stocked seedling nd sapling stands of ine under partial can-py of sawlog-size rees.	Remove overstory trees and treat young pine stands as described on page 10.

Oak-Pine Sites

tand Description	*Prescription*
Iature stands with at east 300 seedlings or 50 saplings per acre of esirable species and orm.	Harvest or kill all overstory trees and release pine and desirable hardwoods with herbicides.
Iature stands but with esirable reproduction nadequate to form new tand.	Harvest or kill all hardwoods, and all but 10 to 12 pine seed trees per acre. Prepare site for pine regeneration. Or clear-cut and direct-seed pine.

Pole stands (30 to 45 years old) and immature sawtimber stands with more than 70 square feet basal area per acre of potential crop trees.	Select potential crop trees (favoring pine where possible) and provide release on 2 or 3 sides by harvesting or killing competing trees. Leave 65 to 75 square feet basal area per acre depending on tree size and stand composition.
Pole or immature sawtimber stands with 50 to 70 square feet basal area per acre of potential crop trees.	On average or better sites stocking density will reach acceptable level within 10 years. Release potential crop trees by sale or TSI, favoring pine trees. In next cut, reduce basal area to 65 to 75 square feet basal area per acre.
Pole or immature sawtimber stands with only 30 to 50 square feet basal area per acre of potential crop trees. Balance of stand inferior-quality hardwoods.	On most sites very little investment can be justified in such stands until more trees are large enough to sell. Then harvest merchantable hardwoods and kill any others that compete with crop trees. These marginal sites usually are better suited for pine than hardwoods, so plan to convert to pine at maturity, usually by direct seeding.
Sapling stands with 150 or more potential pine or oak crop trees per acre.	Release about 150 potential crop trees per acre with herbicides. Provide 3 to 5 feet of crown growing space on all sides of these trees.

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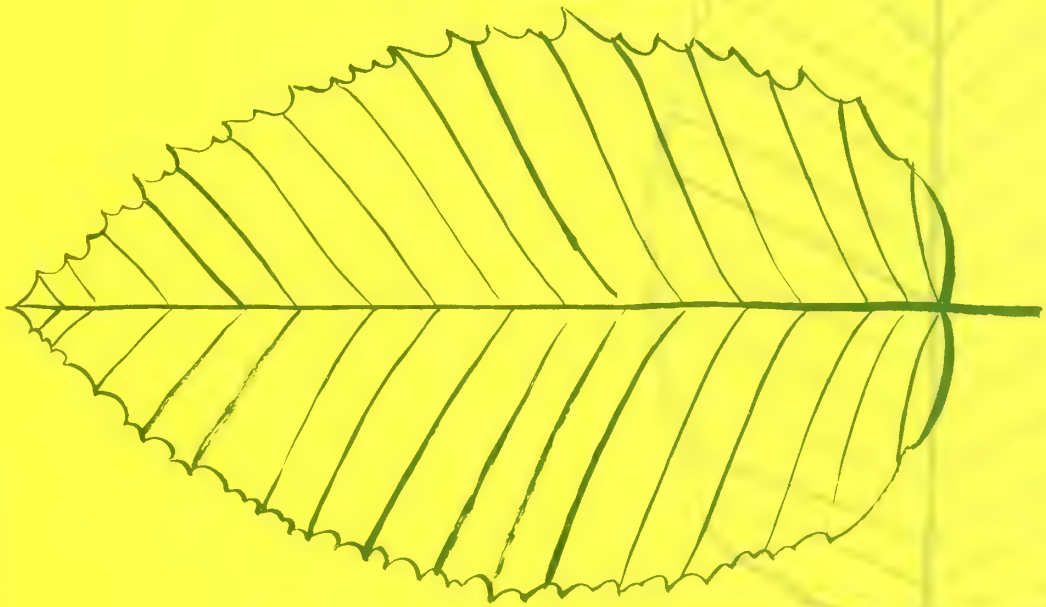
SELECTING SUPERIOR YELLOW BIRCH TREES



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Selecting Superior Yellow Birch Trees
A Preliminary Guide

Knud E. Clausen and Richard M. Godman

THE NEED FOR THIS GUIDE

Most tree improvement programs have been primarily concerned with the fast-growing, highly productive softwoods. However, since hardwoods are well adapted to the sites they now occupy on about half of the commercial forest land in the United States and support an increasingly important segment of the forest industry, genetic improvement of hardwoods is important also. Several species have as good a growth potential as many softwoods, and high-quality hardwoods probably exceed most softwoods in value per acre. For these high-value hardwoods the emphasis should be on tree quality rather than on faster growth and higher yields.

Yellow birch (*Betula alleghaniensis* Britt.), a valuable component of the northern hardwoods, produces heavy, hard, and strong wood which machines well and takes a beautiful finish. High-grade sawlogs, and veneer logs in particular, command high prices, but the supply of high-quality logs is decreasing rapidly. To satisfy future demand for quality products, we must develop improved planting stock and learn how to establish and manage yellow birch plantations.

The first step in a tree improvement program is to locate the best trees available. These superior trees are phenotypic selections and not of proven genetic worth. Next the selected trees are tested for their genotypic superiority — that is, their ability to transmit the desired characteristics to their progeny. During this phase of the program, we learn which characteristics are under strong genetic control. Finally, the superior genotypes are screened out and interbred, naturally or artificially, to produce genetically improved seeds or seedlings.

Only the selection phase is considered here. Rudolf's selection guide for Lake States trees did not include yellow birch.[1] Pitcher and Dorn gave criteria for several hardwoods, including yellow birch, but did not stress the quality characteristics.[2] This publication provides more detailed information on characteristics to look for in selecting superior yellow birch trees.

WHERE TO LOOK

The search for superior yellow birch trees should start in the best stands available. Since variation between stands is a product of both heredity and environment, selection should be relative to the best trees in a given area rather than to absolute numerical standards. If at all possible, selections should be made in stands where comparison trees are available. Only in special cases should isolated trees growing either among other species or in the open be selected.

Selections are easier to make in even-aged stands, but these are usually in the younger age classes. The age of the superior tree candidates should preferably be between 35 and 125 years. Trees younger than 35 years may not yet have had a chance to show their full potential, and old trees are difficult to propagate vegetatively. These age limits are not absolute, however, and outstanding trees younger than 35 or older than 125 years should be reported.

[1] *Rudolf, P. O. 1956. Guide for selecting superior forest trees and stands in the Lake States. U.S. Forest Serv. Lake States Forest Exp. Sta., Sta. Pap. 40, 32 pp., illus.*

[2] *Pitcher, J. A. and D. E. Dorn. 1967. A new form for reporting hardwood superior tree candidates. Fifth Central States Forest Tree Improvement Conf. Proc., Wooster, Ohio, October 1966, p. 7-12.*

WHAT TO LOOK FOR

General Considerations

Yellow birch superior tree candidates should be healthy and vigorous dominants. They should be free of cankers, die-back, and other evidence of disease or insect injury; absence of this kind of injury may indicate that the trees possess some degree of resistance to insects or disease. Although defoliating insects like the birch skeletonizer (*Bucculatrix canadensisella* Cham.) and the birch leaf miner (*Fenusa pusilla* Lep.) seldom kill the trees, they reduce growth. The infestations also weaken the trees and make them more susceptible to attacks by other insects (e.g., birch scale (*Xylococculus betulae* Perg.)) or diseases.

A superior tree should be an average seed producer. While seed production probably is less important than tree quality and growth rate in the initial screening of candidate trees, this characteristic cannot be ignored. It is important to select trees that appear to flower regularly. On the other hand, trees that flower very abundantly may be undesirable since the production of large seed crops usually results in some growth reduction. Because of the periodicity of seed years, fruitfulness cannot always be assessed when the tree is first selected but the tree should be checked for its seed production at a later date.

Characteristics Affecting Tree Quality

Stem Characteristics

Although the characteristics of the entire stem must be considered in making selections, the first two logs (33 feet) are most important since this part of the tree yields the most valuable products. (Figs. 1-3 on pages 3 to 5 illustrate good and poor stem and crown characteristics.)

The bole should be straight. The straighter the log, the less waste in peeling for veneer or sawing for lumber. Even small crooks are objectionable. There should be no lean or sweep, since these deviations lead to the formation of tension wood, which causes shearing in veneer and warping, checking, and cupping in sawn lumber. Sweep also results in volume losses. Furthermore, the veneer in each end of a log with sweep will be cut across the fibers, leading to a degrade in veneer quality. For these reasons, logs with sweep are scaled at less than actual volume. Trees with excessive butt flare should not be selected since there may be some cutting across fibers as there is in logs with sweep.

The stem must be round. Many yellow birch stems are not truly round in cross section but have one flat side. The cause of this is uncertain, but it may be related to conditions of the crown. There is very little waste in rotary-cutting a round veneer log. The ratio between the smallest diameter and the largest diameter at any given point along the stem can be used as an index of roundness. A perfectly round stem will give a ratio of 1.00, and selected trees should have a ratio as close to this figure as possible, preferably not less than 0.95. The trees should be checked for any "flat" areas high on the stem. These are undesirable, partly because they may be indicators of disease.

The bole should have very little taper. Although proper silvicultural treatments may provide some control of stem form (pruning, for example, tends to decrease the amount of taper),[3] their effects may be too small to be of practical importance. Trees tapering more than 2 inches in 16 feet should not be selected.

A superior yellow birch stem should have straight grain. Logs with spiral or other unusual grain patterns are difficult to process for veneer except by slicing; since most yellow birch veneer is rotary-cut, unusual grain patterns degrade log quality.

[3] *Larson, P. R. 1963. Stem form development of forest trees. Forest Sci. Monog. 5, 44 pp.*

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FIGURE 1. This tree is undesirable because it has a short bole, repeated forking, and acute branch angles.

Spiral grain, "wavy grain," and irregular grain patterns in general can usually be detected on the outside of the tree. Detection is easiest in trees with fairly smooth bark. For example, small "bumps" or undulations on the surface of the bark are indicators of so-called "wavy grain," one of the greatest problems in the veneer industry. Since much of the cutting is across the fibers, it raises rough spots which either shear or at best are exceedingly hard to finish. Buyers for veneer mills will usually refuse to buy otherwise perfect logs if they have this defect, which may be overlooked by or appear unimportant to the seller. As a general rule, selections should be made among smooth-barked trees where there is less chance of overlooking unusual grain patterns.

Another reason for avoiding rough-barked trees is that they may be infected with birch scale. This insect causes roughening of yellow birch bark, but is otherwise difficult to detect. Since the insect also spreads *Nectria* spores, birch scale may be more important than commonly realized. Smooth bark may thus indicate greater resistance to the insect.

Trees should not have defects such as seams, bark distortions, or bird peck. In processing veneer logs, open or overgrown seams cause loss of volume due to shearing, or because of the presence of stain or overgrown bark. In other types of logs, deep seams, particularly when associated with rot, will reduce the scaled volume. Seams are usually indicators of some internal stress in the wood or of partial healing of scars and sunscald injuries.

Bark distortions may indicate buried defects such as epicormic buds, knots, or other irregularities that are undesirable in veneer logs. Bird peck, caused by sapsuckers, results in staining of the wood or, in severe cases, in

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FIGURE 2. A desirable but not perfect tree. The stem is well-pruned, round, and with little taper, but it has small crooks in the second log. The crown has very good proportions (crown length is 25 percent of tree height and crown diam./d.b.h. is 20:1), excellent apical dominance, small branches, good branch angles, and good density. What appears to be a fork halfway up the tree is actually part of the stem of another tree.

ring shake.[4] Since the birds seem to prefer certain trees there may be heritable chemical differences between trees; therefore, trees with bird peck should not be selected.

Good self-pruning is a desirable trait; but it is generally difficult to see whether good pruning is due to heredity or to the microenvironment. The amount and type of competition, for example, definitely influences self-pruning. In a tree that has grown a long time in the open, self-pruning may indicate strong genetic control. Such a tree should be selected if it otherwise meets the criteria for a superior tree. In a stand, selection for self-pruning is much more difficult. Some trees retain one or more steep-angled branches low on the stem. Since such branches result in large knots, these trees should be avoided.

Forking is particularly undesirable. Low forks cause a serious volume loss of potentially high-quality wood. Forked trees also tend to break from wind and ice; this usually results in some loss of the crown and subsequent growth reduction, and provides entrance ports for fungi and other disease organisms. There is good evidence that forking is under strong genetic control in most forest tree species, and individuals with repeated forking should, therefore, be avoided. Trees with a fork in the first two logs should never be accepted.

[4] *Shigo, A. L. 1963. Ring shake associated with sapsucker injury. U.S. Forest Serv. Res. Pap. NE-8, 10 pp., illus. Northeast. Forest Exp. Sta., Upper Darby, Penn.*

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FIGURE 3. Two trees with good stem characteristics and poor crown characteristics. Both trees have straight and round boles but too long crowns (crown length is about 45 percent of tree height). The forked tree on the left has large branches, acute branch angles, and too broad a crown (crown diam./d.b.h. = 28:1) of average density. The tree on the right has small branches but acute branch angles, average crown width (crown diam./d.b.h.= 25:1), and good crown density.

Forks may be caused by frost damage to buds, ice and wind injury of buds and shoots, and other climatic factors. Absence of forking may thus indicate possible resistance to environmental hazards and a desirable genetic make-up of the tree.

A yellow birch tree with any of the following conditions should be considered as forked:

1. The smaller of two adjacent leaders is at least two-thirds the diameter of the larger one.
2. The angle between a branch and the main stem is less than 30 degrees.
3. The diameter of the main stem above the branch juncture is at least 25 percent smaller than the stem diameter below the juncture.

Crown Characteristics

Good apical dominance — a central stem to the top of the tree — is a highly desirable but uncommon characteristic in yellow birch, perhaps due to the indeterminate growth habit of the species. Because it is rare, a thorough search will be required to find trees with good apical dominance. Superior tree candidates should preferably maintain a central stem to three-fourths of their total height. Only trees with a central stem to at least half of the total tree height or 33 feet, whichever is greater, should be accepted.

Trees with small branch angles should not be selected. Trees with large branch angles appear to have less breakage from ice and snow than those with more acute angles. Branch angle also affects stem taper, natural pruning, and knot size. Steep-angled branches are often larger than wide-angled branches, they usually take a longer time to die and fall off, and they leave large knots which are grading defects in hardwood logs. Large knots, whether from natural or from artificial pruning, also take more time to heal over than small knots. Since branch angle appears to be under strong genetic control, selection for large branch angles should result in considerable improvement in this characteristic.

Branch angles seem to be more acute in yellow birch than in many other species. Observations indicate that most mature yellow birches have branch angles between 30 and 60 degrees. Angles between 60 and 90 degrees are apparently rare. Superior trees should have as large branch angles as possible, preferably 45 degrees or more; trees with branch angles of 30 degrees or less are unacceptable.

Branch diameter should be small. Branches of small diameter leave small knots, which heal over faster than larger knots. Small branches are also cheaper to remove than large branches. There may be a favorable relationship between branch diameter and branch angle in yellow birch: i.e., trees with small diameter branches also appear to have large branch angles. If these two branch characteristics should, in fact, turn out to be correlated with each other or even linked genetically, selection for them should lead to rapid improvement.

A sawlog-sized tree should have *no* branches within the first two logs. A branch in the live crown should preferably not exceed one-sixth the diameter of the main stem at the point of branching; one-fifth would be the upper limit acceptable. Thus, a tree with a branch larger than 2 inches in diameter at a point where the stem diameter is 10 inches would be rejected.

Characteristics Affecting Growth

Although the quality of the stem is the first concern, characteristics that influence spatial requirements, growth rate, and total wood production cannot be ignored. Age of the candidate tree is important because of the large variation in age among yellow birches of the same diameter. For example, trees 20 inches in d.b.h. growing in the same stand may vary in age from 100 to 235 years.[5] The selected tree should, therefore, be of the same age, or younger than, at least three other yellow birches of comparable height, diameter, and crown size. The comparison trees should be growing within a radius of about twice the height of the superior tree.

Crown size is an important characteristic in yellow birch due to its effect on growth rate and total growth. A tree with crown size below a certain limit will have a slow growth rate and may die of suppression. On the other hand, yellow birch crowns appear to respond well to release. Both the length and the width of the crown are important. Although a crowded tree may compensate for its narrow crown by increasing the length of the crown, the crown should have certain desirable proportions.

The length of the live crown should be approximately 35 to 40 percent of total tree height. The larger ratio would be acceptable for small trees, whereas larger trees should have a crown ratio of 35 percent and certainly not less than 25 percent. The length of the live crown should be measured to the level of the lowest leaf-bearing surface, not to the point of attachment of the lowest live branches. Measurements based on the origin of the lowest live branch will overestimate the active part of the crown. In measuring crown length, leaf-bearing epicormic branches should be ignored.

The width of the crown is important since a narrow-crowned tree that is growing as well as a wide-crowned tree occupies much less growing space, thus allowing a larger number of trees per acre. There is, however, a limit to how narrow the crown can be and at the same time maintain the tree in good growth. Experience has shown that the average yellow birch has a ratio of crown diameter to d.b.h. of 25:1. This ratio tends to be somewhat larger in younger trees, but a superior tree candidate 8 inches or less in diameter should not have a ratio larger than 22:1. Trees of larger diameter should have a ratio of 20:1 or preferably 18:1 to qualify as superior trees. A selected tree should be able to maintain this ratio while under moderate to heavy competition. If the competition is severe the crown will usually be too small, and the tree may respond by developing epicormic branches, which are undesirable in quality trees. The presence of epicormic branches usually indicates undesirable crown characteristics.

Dense crowns should be favored. Experience has shown that dense crowns usually produce average or better than average tree growth; thin crowns are associated with slow growth (fig. 4). So far no practical method of measuring crown density in the field has been developed, but it is possible to distinguish between dense and thin crowns. When the trees are leafless, crowns with many small branches of lower orders appear dense when viewed against the sky while crowns with mostly first- and second-order branches appear loose and thin.

Growth rate is less important than tree quality, but a superior tree should show average or better than average growth. While slower grown logs are somewhat easier to cut, faster grown logs present no particular problems in veneer production. A tree with a fairly dense crown of the size recommended above and growing under moderate competition should have grown at least 2 inches in d.b.h. in either of the last two 10-year periods. Such trees will, generally speaking, appear vigorous. Observations suggest that the

[5] *Unpublished information on file at the Institute of Forest Genetics, Rhinelander, Wis.*

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FIGURE 4. A dense crown (left) and a thin crown (right). The crown on the left has more male catkins than the one on the right, but its denser appearance is primarily due to the presence of more twigs of lower branch orders.

vigor of yellow birches 12 inches d.b.h. and above can be judged by the appearance of the bark. Fast-growing, vigorous trees tend to have fairly smooth or extensively peeling yellowish bark, while slow-growing trees usually have rough, dark bark broken into flat plates. For example, a smooth-barked 14-inch tree averaged 0.25 inch in diameter per year whereas an adjacent rough-barked tree only grew 0.10 inch per year.[6] It may therefore be wise to avoid rough-barked trees.

Unusual Characteristics

Occasionally one finds a single yellow birch tree growing and competing successfully in stands of almost pure sugar maple. These trees may have a special competitive ability which conceivably could be a characteristic under genetic control and thus worth selecting for. If such trees are of high quality and otherwise satisfy the criteria for superior trees they should be selected and recorded as having this special attribute.

While irregular grain patterns as a rule are undesirable, trees with figured woods such as "curly," "flame," and "wavy" grain may be used for specialty veneers or solid-wood furniture. Such trees should, therefore, be reported.

Trees with other unusual characteristics should also be noted and reported. Examples are trees with unusual bark, branching habit, leaves, or fruits, and trees with especially early or late budbreak, flowering, fall coloration, or leaf fall. Most of the unusual characteristics will probably be of little or no practical value but may be useful in inheritance studies.

SUMMING UP

Procedures to follow and characteristics to consider in selecting superior yellow birch trees can be summarized as follows:

1. Locate the best 35- to 125-year-old stands in your area.

2. Look for dominant trees free of diseases and insects and, if possible, with good seed production.

3 Make the first selection on the basis of tree quality. Consider these stem and crown characteristics:

a. The stem should be straight and round, with little taper, and have straight grain and good self-pruning. It should have no forks or defects such as seams, bark distortions, or bird peck.

b. The crown should have good apical dominance. The branch angle should be as large as possible and the branch diameter as small as possible.

4. When trees of high quality have been selected, compare each superior tree candidate with three comparison trees within a radius of about twice the height of the selected tree. The following traits primarily affecting growth should be considered:

a. The selected tree should be of the same age, or younger than, the comparison trees.

b. The length of the live crown (measured to the level of the lowest leaf-bearing surface) should be 40 percent or less of total tree height in

[6] *Unpublished information on file at the Institute of Forest Genetics, Rhinelander, Wis.*

younger trees and between 35 and 25 percent in older trees.

c. The ratio of crown diameter/d.b.h. should not exceed 22:1 in trees 8 inches or less in d.b.h. and should range from 20:1 to 18:1 in larger trees. Trees with epicormic branches should be avoided.

d. Only trees with average to good crown density should be selected.

e. A superior tree should have average or better than average growth rate and should have grown at least 2 inches in d.b.h. in either of the last two 10-year periods. Smooth, yellow bark may indicate good tree vigor.

5. Give special consideration to trees competing successfully in sugar maple stands, and report trees with figured wood or other unusual characteristics.

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Stabilizing Eroding Streambanks

IN SAND DRIFT AREAS OF THE LAKE STATES

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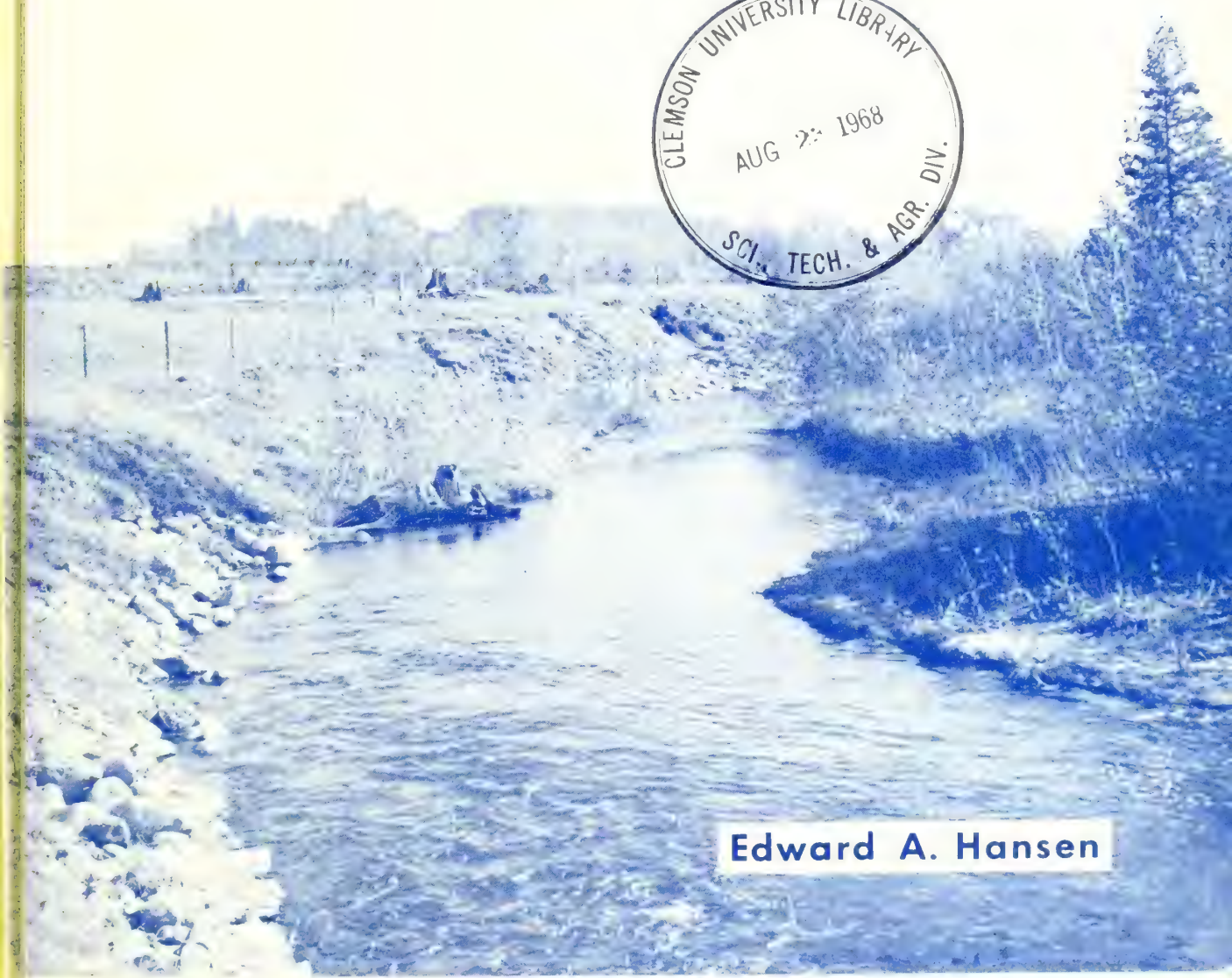

Edward A. Hansen

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F-517762

Cover photo: Bank stabilized by rock rip-rap.

NOTE: The author is Associate Hydrologist headquartered at the Station's field office in Cadillac, Mich.

NORTH CENTRAL FOREST EXPERIMENT STATION
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Stabilizing Eroding Streambanks In Sand Drift Areas of the Lake States

Edward A. Hansen

Streambank erosion has long been a subject of concern to land managers. Some work in this field has been published — much has not. Consequently, much eroding bank stabilization is planned and carried out without benefit of previous experience.

This paper summarizes the present state of knowledge of eroding-bank stabilization on small streams in the sand glacial drift areas in the three Lake States: Minnesota, Wisconsin, and Michigan (Fig. 1). "Small streams" are those that can be waded or used only by small pleasure boats. Some information on lakeshore stabilization in the Lake States is also included.

The recommendations given in this paper are a summary of published information (see Literature Cited, p. 11) supplemented by the experience of many individuals throughout the Lake States who have worked on bank stabilization.

REASONS FOR STABILIZING BANKS

Protect Streamside Values

Streamside values sometimes endangered by bank erosion include buildings, campgrounds, stream access points, and roads (Fig. 2). For these it is easy to determine whether the cost of stabilizing the bank will be less than the anticipated future loss to the streamside value. Although the alternative of moving the item that is being threatened by bank erosion should be considered, it is usually most economical to stabilize the bank.

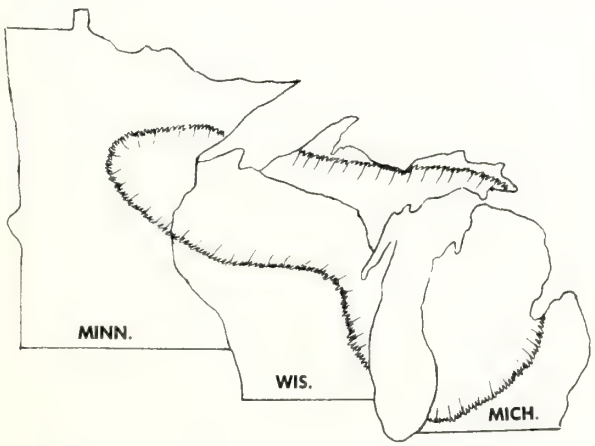

FIGURE 1. — Area of sand glacial drift in the Lake States.

Most Lake States streams are being used increasingly for canoeing, fishing, and other recreational purposes. It is not presently known whether revegetation of all eroding banks will increase or decrease the scenic value that recreationists place on the stream (Fig. 3). As soon as sufficient information on this aspect becomes available, the role of the eroding bank in the total aesthetic picture of the stream should be considered.

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FIGURE 2. — Eroding bank endangering a cabin. Cost of bank stabilization is minor compared to such an on-site value.

F-517756

FIGURE 3. — Would stabilization of this bank change the wilderness setting of this stream?

Reduce Sediment Load

The more comprehensive bank stabilization projects on small streams usually are intended to reduce the sediment load of the stream. This may be done to slow down sedimentation in downstream reservoirs or lakes, or to reduce sedimentation in the stream channel and thereby minimize flood damage, or, more commonly, in the sand drift area of the Lake States to improve the stream habitat for fish (primarily trout).

Again, it is relatively easy to assess the effect of floods or sedimentation on property values and reservoir storage capacity. However, the effect of sediment on stream habitat and on the fish population is much more complex (Fig. 4). Sediment is only one of many factors that may limit the fish population in a particular stream. Suspended sediment concentration in the streams of the Lake States glacial drift area is generally low except during floods. These low concentrations probably do not limit the trout population in most instances. However, the larger sand-size material moving along the bed of the stream may be much more damaging. This coarse material covers spawning beds, fills holes used for cover, and scours food organisms off the bottom of the stream (Cordone and Kelley 1961). However, it is not known to what extent these limit the trout population in any particular stream. Studies have shown that bank stabilization will only partially reduce a stream's sediment load (Parsons, Apmann, and Decker 1964; Striffler 1964, 1965) probably less than 50 percent in most streams. But it is not known whether such a partial reduction in coarse sediment will result in increased trout population.

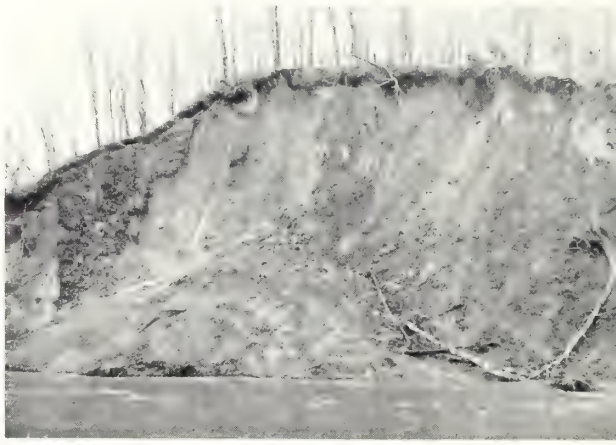

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FIGURE 4. — One of many eroding banks on this stream. Is the effect of bank stabilization on the fish population worth the cost of control?

TREATMENT PLANNING

Stabilizing an entire section of a stream is costly. There are several ways to reduce this cost or to increase the effectiveness of the treatment with the same amount of money.

One way is to begin bank stabilization at the head of the stream and work downstream. This permits the treated section of stream to attain the maximum benefits of bank stabilization before the entire stream is finished. Thus, if work is halted for any reason before the whole iob is done, at least a section of the stream has been completed.

Eroding-bank treatment usually consists of stabilizing the waterline with rock or other heavy material and then sloping the upper bank and seeding. A way to save money, however, when the major objective of the stabilization program is to reduce sediment, is to forego upper bank sloping and seeding. Experience throughout the Lake States has shown that once the toe of a bank is stabilized, the bank will revegetate naturally (Red Clay Interagency Committee 1964; Urie 1967) (Fig. 5). Thus upper bank treatment is not mandatory in stabilizing eroding banks.

Human traffic is becoming increasingly important in bank erosion and hence bank stabilization planning. When the bank is used heavily by people it is usually sloped and seeded. In addition, other things may be necessary to insure successful stabilization: fences or thorny bushes may be used to exclude people, or signs and footpaths used to direct people across or around the bank. Rock rip-rap should be large enough so that it is not easily moved by hand on those banks readily accessible to people.

F-517758

FIGURE 5. — A bank that revegetated naturally following rock rip-rapping below the waterline 6 years previously. Note natural appearance of bank.

BANK STABILIZATION TECHNIQUES

In this discussion the "lower bank" is that portion frequently covered by flood water. Much effort is usually required to stabilize this part of the bank which comes in periodic contact with high velocity streamflow. This is in contrast with the "upper bank" which is seldom, if ever, exposed to direct erosive action of the stream and for which vegetaton alone usually provides adequate stabilization.

The eroding bank usually has to be sloped to a suitable angle before any structural work can be done. In general, gently sloping banks are more stable for rip-rap or any other material and hence have fewer failures. The following length-to-height ratios for streambank slopes can guide first attempts at bank stabilization in unfamiliar areas:

Soil texture	*Maximum slope*
Clay	1-1¼ : 1
Loam	1½-2 : 1
Sand or gravel	2-4 : 1

Low banks should be completely sloped. Only the lower portion of high banks needs to be sloped, however, leaving the upper bank to revegetate naturally.

One of the techniques used in sloping the lower portion of high banks is to construct a bench along the bank with fill material obtained from across the channel (Fig. 6a). The bench provides working space for men and equipment and should be at least as high as the high water mark of the normal annual

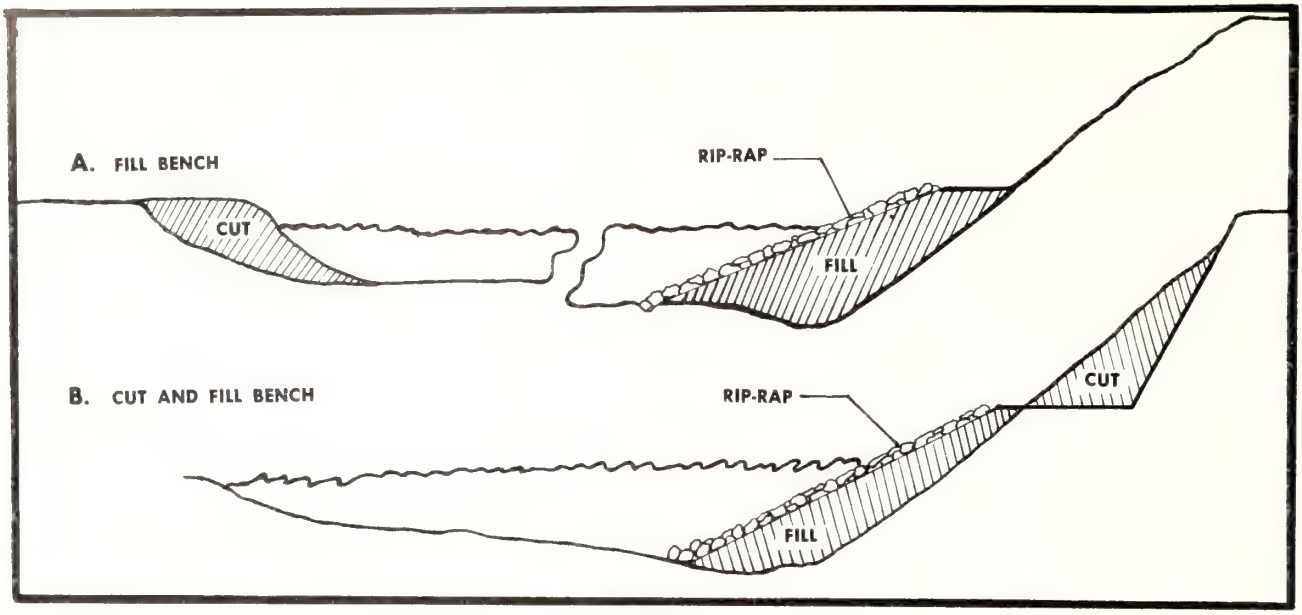

FIGURE 6. — Bench construction on high banks.

flood. The material excavated from the streambed and bank opposite the eroding bank compensates for the reduction in channel cross section due to the bench fill.

An alternative method is to cut the bench into the eroding bank, removing the cut material altogether (Silberberger 1959) or using it to construct the bench and slope the lower bank (Fig. 6b). This latter method causes a narrowing of the stream channel and should only be attempted when the streambed and bank opposite the eroding bank are composed of easily erodible alluvial deposits. In such instances, the narrowed channel cross section will readjust itself during the next flood. After construction of the bench, the lower bank must be stabilized with rock rip-rap or some other material.

Lower Bank

A wide selection of material and techniques is available to use for bank stabilization. Of these, rock rip-rap has been, by far, the most commonly used in the Lake States. Less common are gabions, stumps, and cut-tree revetments. These types of structures are most popular because the materials are available locally, the cost is low compared with other types of structures, the stabilized bank blends in well with the surroundings (Fig. 5), and failure of the structure usually does not immediately endanger life or property. Since these structures are used for most bank stabilization on small streams, this section will be limited to them. For information on more durable and expensive structures using concrete, steel, or asphalt, refer to the following publications:

1. Bank and Shore Protection in California Highway Practice. State of California, Department of Public Works, Division of Highways, Nov. 1960.
2. Watershed Structural Measures Handbook Chapter 2534, USDA Forest Service, Feb. 1959.

Rock Rip-Rap

Rock rip-rap is used most in bank stabilization when the material is readily available; it is easily placed and durable. Several factors need to be considered in order for the rip-rap to adequately protect the bank.

The required thickness of the rip-rap blanket depends on bank slope, stream velocity, and the size, shape, and specific gravity of the rock used. An indication of the size of rock required can be obtained from a graph published by the California State Division of Highways (California Highway Division 1960) (Fig. 7). However, this graph should

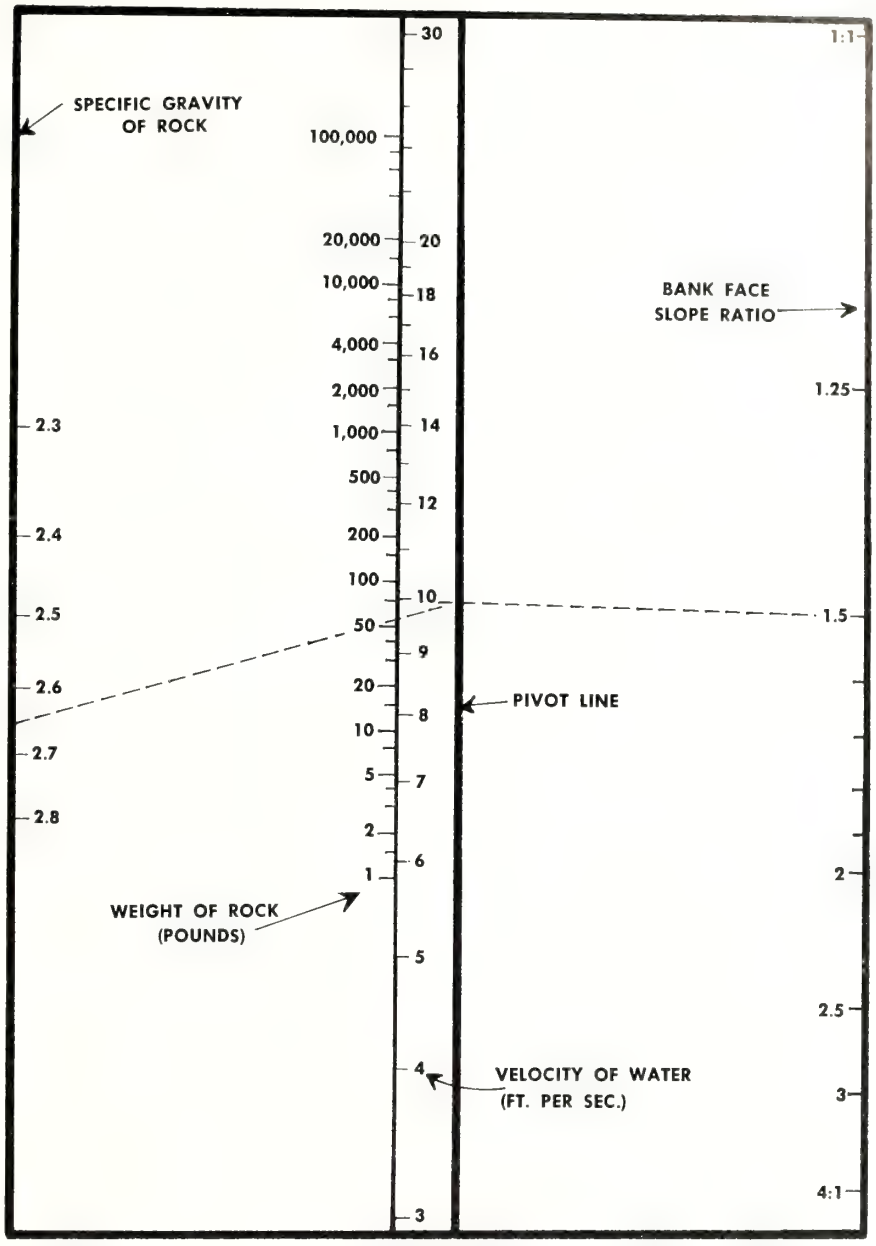

FIGURE 7. — Alignment chart for determining weight of stone to be used for rip-rap.
Example: Find bank slope ratio (1.5:1) on righthand scale. Extend line to appropriate water velocity (10 feet per second) on right side of center scale. Find specific gravity of rock (2.65) on lefthand scale. Extend line to intersect first line at "Pivot line." Read weight of rock (57 pounds) where second line crosses center scale.

be considered only as a point of departure on which to base rip-rap design in the Lake States. The graph shows the minimum weight of the rock that will not be moved by the stream under the design conditions. Two-thirds of the rock should be heavier than the minimum.

The thickness of the rip-rap blanket should be 1.5 times the diameter of the smallest "immovable" rock if the rip-rap is hand-laid and 1.9 times the diameter if rip-rap is dumped and spread with a bulldozer (Fig. 8) (California Highway Division 1960). Minimum recommended thickness of rip-rap is about 12 inches (Silberberger 1959; U.S. Forest Service 1958). In general, the largest rock and the thickest portion of the rip-rap should be at the toe of the slope and where the stream's curve is sharpest. Also, larger rocks should be placed on the face of the rip-rap with the smaller rocks laid underneath and used for chinking.

Provisions must be made to insure that the toe is tied in well to the streambed. A trench should be excavated so that the toe of the rip-rap extends below the scour level of the streambed (Fig. 8). When it is impractical to excavate a trench, enough rock must be dumped at the toe to provide a firm foundation, even following scour and consequent moving and settling of rock that will take place during future floods.

Erosion usually occurs at the outside bank of a stream bend where the water flows fastest. Rip-rap should be extended completely around the bend to protect the bank from the increased velocity. Also, the surface of the rip-rap should be as rough as possible to help counteract this acceleration. However, the downstream end of the rip-rap should be smoothly tied into the natural bank with smaller size rock so as not to create turbulence and eddies that might start a new point of erosion. Failure to do this may result in washouts and higher maintenance costs.

A "backing" or "filter" material is often needed to prevent erosion and loss of bank material between the larger rocks when there is much water turbulence. A 4- to 6-inch layer of gravel underneath the rip-rap will keep the finer textured bank material from washing through the rip-rap (U.S. Forest Service 1958). Durable fine-mesh cloth can also be used as a filter. A filter layer is not needed when the water velocity and turbulence are low or when there is a wide distribution of rock sizes in the rip-rap.

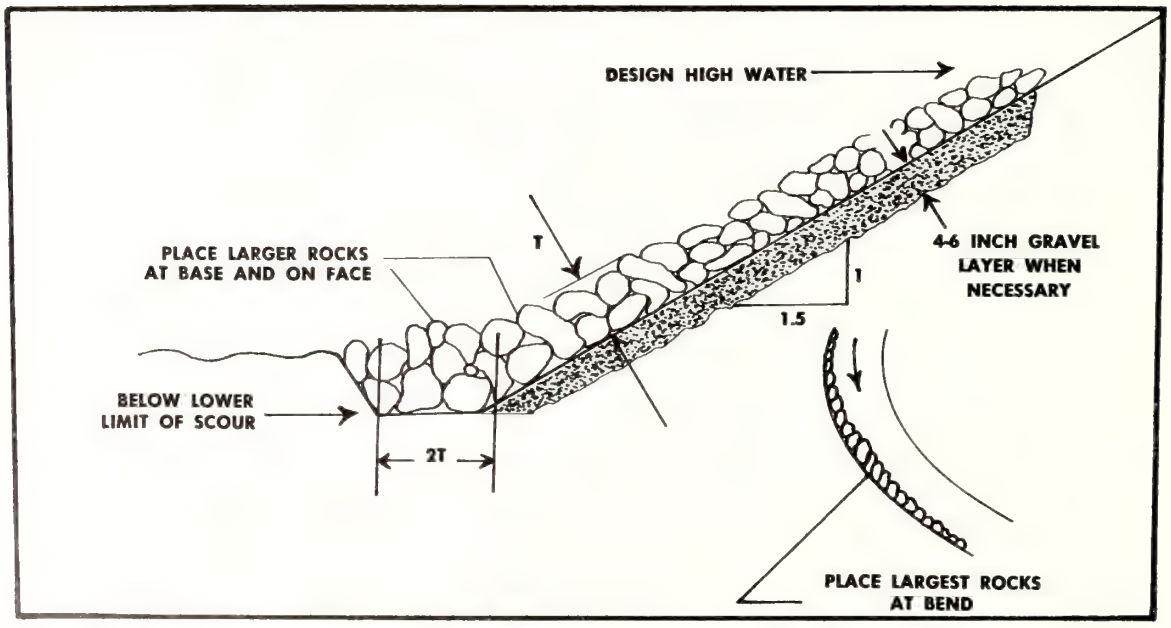

FIGURE 8. — Dimensions of typical rock rip-rap blanket. T is equal to or greater than 1.5 D where "D" is diameter of average size rock. When rock is spherical cobbles, or when machine-placed, T = 1.9 D.

Grouted Rock Rip-Rap

When large rocks are not available, smaller size rocks bonded together by grouting (cementing) may be used to prevent movement. Grouted rip-rap need not be as thick as loose rip-rap and the bank can be steeper. Disadvantages are increased cost and "unnatural" appearing banks.

Grout can only be applied out of the water. This limits its use to the portion of the bank above the low-water level. The part of the bank under the water would have to be stabilized with either larger rock or with a combination of rock and wire mesh.

Grout should penetrate from 6 inches for cobble-size material to 18 inches for rock of ½-ton size (California Highway Division 1960). The rocks to be grouted should be clean and moist. It is usually desirable to decrease stream velocity adjacent to the bank. Therefore, grout should be made with a fairly coarse aggregate (up to three-fourths inch) to increase the surface roughness of the bank. The surface rocks can project one-fourth to one-third of their diameter from the grout as an additional aid in decreasing the adjacent stream velocity.

Rock Rip-Rap and Wire Mesh

Wire mesh may be laid over a rip-rapped slope where the stone is too small to provide adequate protection by itself. This technique is generally better than grouting when very fine stone is used or when the bank is composed of easily erodible material. The simplest technique is to lay wire mesh over the loose stone and pin the wire in place with reinforcing rods (Fig. 9a) (California Highway Division 1960). A concrete-filled pipe or similar weight can be used to hold down the lower edge of the wire wesh. Some vegetation usually becomes established which aids in stabilization and provides a more natural appearance.

More stability may be obtained by placing a sheet of wire mesh underneath the rip-rap with a second sheet on top. The two pieces of wire mesh can then be fastened together into a "mattress" with the rock held in between (fig. 9b). This permits some shifting of the entire structure without undue loss of stone. Mattresses can be used along the toe of a bank to provide flexible protection where scour occurs. As scour proceeds along the lower edge of the mattress, the mattress settles until it reaches the lowest level at which scour takes place. Mattresses have not been successful on bends of streams because scouring lengthens the outer bank and causes the settling mattresses to pull away from each other (California Highway Division 1960). But they have performed satisfactorily along relatively straight reaches of stream.

The wire mesh can be formed into baskets first and then filled with rock. The baskets or "gabions" can be used to cover the bank in a fashion similar to the mattresses, or they can be stacked vertically to form walls (Tobiaski and Tripp 1961). A disadvantage of gabions is their unnatural appearance (Fig. 10). The wire mesh should be small enough so that most of the rock cannot pass through. The strength and durability of the wire are largely a matter of judgment and will depend on the importance of the structure and its desired life.

Tree and Stump Revetments

Whole trees can be place along the edge of the bank and cabled together (Fig. 11). This type of structure needs continual maintenance as individual trees rot and require replacement. However, it may be a desirable technique to use in situations where rock is not available.

Stumps cabled to the bank or fastened to piling, provide a moderate amount of bank protection on some slow-moving streams and, in addition, provide cover for fish. This is likewise a relatively temporary stabilization measure compared to using rock rip-rap. However, data are not yet available on the expected life of these structures.

Upper Bank

Revegetation of the upper bank may be left to natural processes or it can be accelerated with combinations of sloping, seeding, fertilizing, mulching, sodding, planting trees and shrubs, terracing, and fencing. The par-

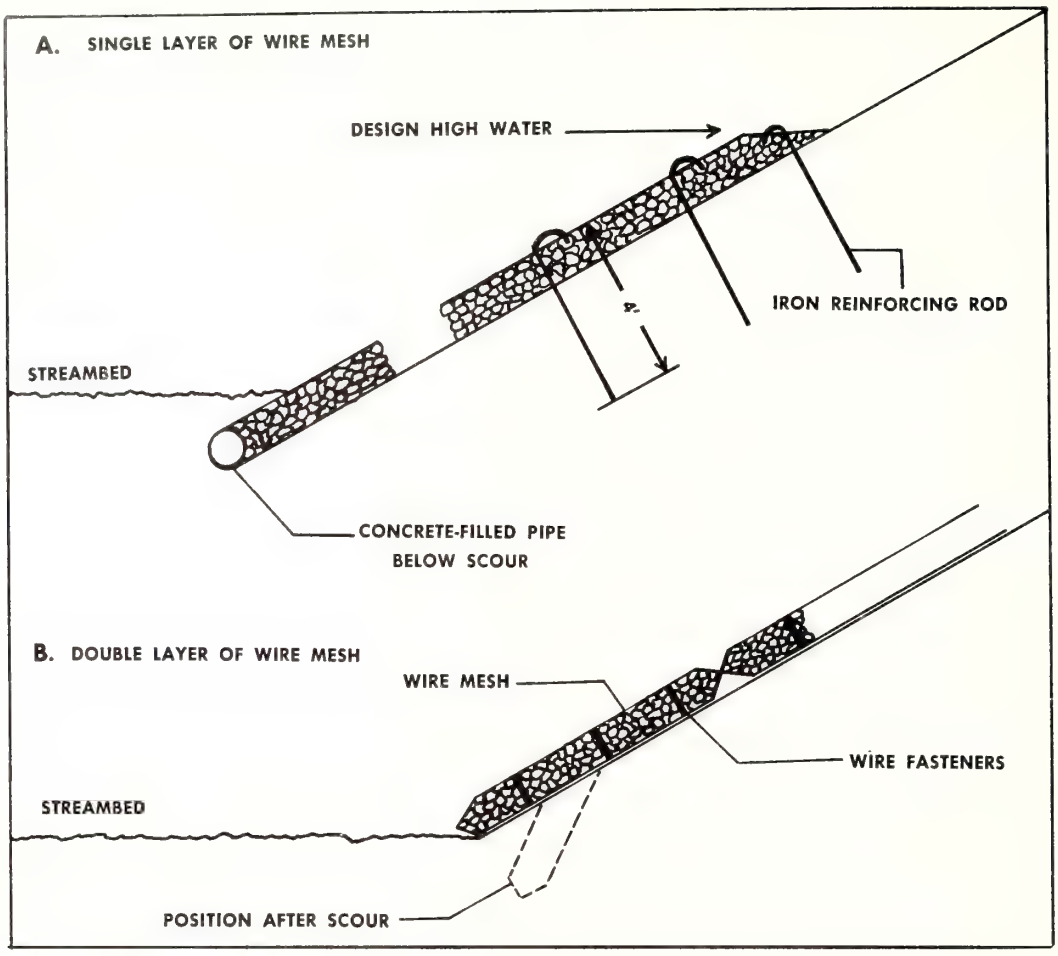

FIGURE 9. — Use of wire mesh to stabilize small rock rip-rap.

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FIGURE 10. — A gabion structure for controlling waterline erosion. The unnatural appearance may be undesirable in some situations.

F-517760

FIGURE 11. — A bank stabilized with whole trees. This structure will need continual maintenance.

ticular combination used depends on the rapidity with which it is desired to revegetate the bank and the anticipated difficulty in establishing vegetation. Three of the most common practices, mulching, seeding, and fertilizing will be discussed in more detail.

Mulching

Mulches are used to stabilize the surface soil, prevent loss of seed, reduce evaporation of water from the soil, and in some cases to increase infiltration of water. Generally, mulches are used above the normal high-water level and are not exposed to stream erosion. However, in some cases vegetation is relied on to stabilize the bank below the high-water level. In those instances, the mulch must provide protection from floods between the time of bank sloping and the establishment of vegetation.

A layer of brush 12 to 18 inches thick can be used when occasional protection is needed from moderately fast water or ice flows (Edminster *et al.* 1949). The brush should be held down with rope tied to stakes driven into the bank, so that floods during the first year or two do not carry the brush away. As the vegetation becomes established, it will provide protection for the bank and help retain the remaining brush. Willows or other water-tolerant shrubs can be planted near the waterline for continued protection from ice following deterioration of the brush mulch. Native species usually give the best results.

Straw is probably the most commonly used mulch due to its availability and low cost. Application rate varies from 1½ to 2 tons per acre (Red Clay Interagency Committee 1964). A straw-asphalt mixture has proved successful on roadbanks. Water-emulsifiable asphalt applied at a rate of 150 gallons per acre acts as a binder and prevents the straw from blowing or washing away.

A fiberglass product called "glassroot,"[1] gave excellent erosion protection when applied to a drainage ditch on heavy clay near Ashland, Wis., (Red Clay Interagency Committee 1964). It forms a tight bond with the surface of the clay yet is easily penetrated by vegetation. The material is fairly expensive but might be feasible on areas exposed to severe water erosion (Ree 1960).

Many other products have been used for mulching banks. Troy Turf is a jute mat that can be used as a substitute for sod (Allen 1962). Included in the mat are the seed, fertilizer, and a growing medium. The mat is transported in rolls that can be unrolled and fastened to a steep bank. Soil Saver is a heavy jute mesh that can be laid on a newly seeded bank to prevent erosion (Broach and Terrio 1960; Ree 1960). A woodfiber cellulose mulch product (Turfiber) can be sprayed on the bank as a slurry (Harper 1961). Seed and fertilizer can also be mixed in the slurry. These products have been used by highway departments of many States.

Many chemical products have been tested as mulches with widely varied results. Most of these are applied in liquid form and have the object of binding the soil particles together. None has had widespread use on streambanks in the Lake States. Tests conducted with these liquid mulches have had only limited success (Urie 1967).

Seeding

Many different mixtures of grasses and legumes have also been tried. The best seed mixture tested for clay banks near Ashland, Wis., was 50 percent smooth bromegrass (Canadian or variety Sac.), 25 percent Empire birdsfoot trefoil, and 25 percent tall fescue (Alta or Kentucky 31) (Red Clay Interagency Committee 1964). Crown vetch also provided good cover although it took several years for a good stand to become established. Good results have been obtained on glacial till soils with mixtures of tall fescue and crown vetch, red fescue and birdsfoot trefoil, or tall fescue and birdsfoot trefoil (Porter and Silberberger 1960). Reed's canary grass is recommended for use at the waterline of eroding banks.

Seeding rates are generally 20 to 30 pounds per acre. Experience indicates that the banks should be seeded as early in the year as is practical.

[1] *Products named are examples only: their mention does not imply endorsement by the U.S. Department of Agriculture.*

Fertilizing

Fertilization usually increases establishment success. Typical application rates are 500 pounds per acre of 10-10-10 or 5-10-5 (Porter and Silberberger 1960; Red Clay Interagency Committee 1964). However, in one instance at Ashland, Wis., an application rate of 2,400 pounds per acre on exposed clay subsoils resulted in additional improvement in the vegetation. An additional monthly application of ammonium nitrate at a rate of 50 pounds per acre was found necessary on sterile glacial till subsoils until the vegetation was well established (Porter and Silberberger 1960).

CAUSES OF FAILURE

It has been said that "bank protection never has been and never will be an exact science" (Rowe 1953). Due to the complex and often unique characteristics of each bank and the consequent large amount of judgment involved in planning bank stabilization structures, there will always be a certain amount of failure. Some of the more common causes of failure are listed below.

Bank stabilization measures using "temporary" materials may fail when the "temporary" materials begin to disintegrate. In some cases, vegetation which has become established at the waterline in the interim may adequately replace the "temporary" material. However, it is not possible, at present, to predict under what conditions vegetation alone will provide adequate protection.

A bank-stabilization structure may be underdesigned, and "normal" stream discharges cause it to fail. One common cause of failure is due to a rough transition between the downstream end of the rip-rap and the natural bank. The rapidly accelerating stream adjacent to the rip-rapped bank is slowed when it reaches the unrip-rapped rough-walled bank just downstream. This change in stream velocity often produces an eddy which initiates a new point of bank erosion (Fig. 12) (California Highway Division 1960).

Finally, regardless of the effort and expense put into bank stabilization, it should be expected that occasional rare flood events of large magnitude will destroy some of the work. Bank stabilization measures usually are not, and probably should not be, designed to withstand these extreme flood events. A planned maintenance program should be a part of any bank stabilization program.

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FIGURE 12. — Bank failure due to a rough transition between rip-rap and natural bank. The rough transition resulted in the eddy indicated by arrows.

SUMMARY

Bank protection planning balances the immediate real cost of stabilization against a probable future benefit. The immediate cost of stabilization can be estimated fairly accurately and can be improved upon with the experience gained from treating the first few banks. Future benefits, such as protection of on-site values or reduction in reservoir or lake sedimentation rates, can be estimated and expressed in economic terms. However, the possible future benefit from attempting to increase fish population through bank stabilization is obscure. Consequently, present justification of such an objective will have to be stated in qualitative terms such as reduced sediment load or possibly improved fish habitat.

There is a wide variety of stabilization techniques that can be used for bank protection. Rock rip-rap is probably the best material to use for stabilizing the lower bank, since there is little that can deteriorate with time. However, rock of sufficient size and quantity is often difficult to obtain in the Lake States. In such cases, alternative methods employing wire, wood, or live vegetation must be used.

The upper bank will revegetate naturally. However, sloping and application of seed, fertilizer, and mulch will accelerate the revegetation process.

Maintenance should be a planned part of a bank-stabilization program because of the possibility of some structural failure in the future and the start of new points of erosion from normal stream meandering.

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PAPER BIRCH

Its Characteristics, Properties, and Uses

A REVIEW OF RECENT LITERATURE - by Matti J. Hyvarinen

NORTH CENTRAL FOREST EXPERIMENT STATION
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FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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Cover picture: A pure stand of paper birch. Stands such as these have the potential for producing a high proportion of saw logs and veneer bolts.

NOTE: The author is a Forest Products Technologist at the North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture. He is headquartered at the Station's field office in Duluth, Minnesota, which is maintained in cooperation with the University of Minnesota.

Paper Birch: Its Characteristics, Properties, and Uses

A Review of Recent Literature

Matti J. Hyvarinen

Paper birch, *Betula papyrifera Marsh.*, has recently become one of the most abundant species in the Lake States. In Minnesota it ranks third in growing stock volume, after aspen and jack pine (Stone 1966).[1]

This fast-growing, short-lived tree is attacked by many enemies and will not store on the stump. But because of its generally small size, the annual cut is only about a sixth of the desirable cut.

A better knowledge of the species — the resource, silvics, wood quality and properties, and products — should stimulate more extensive use. This paper reviews recent literature on these subjects and points out areas in which additional research is needed.

Resources

The aspen-birch type[2] covers one-third of the commercial forest land in the Lake States (Findell *et al.* 1960, Stone and Thorne 1961, Stone 1966): 7 million acres in Minnesota, and 9.4 million acres divided fairly evenly between Wisconsin and Michigan.

The net volume of paper birch growing stock in the Lake States is about 1.6 billion cubic feet or about one-fourth as much as the volume of aspen (table 1). Both the net annual growth and the annual desirable cut exceed the annual cut by a large amount in every one of the Lake States. The total cut in the three States combined is only 16 percent of the desirable cut.

The sawtimber net volume is about 1.1 billion board feet (table 1). Better use is made of the sawtimber trees than the poletimber trees. The annual sawtimber cut is 35 percent of the desirable cut.

Information for the remainder of the resource section deals only with Minnesota where the most recent survey was conducted (Stone 1966). The paper birch forest type stands are located mostly on good to medium sites:

Site index[1]	*Site class*	*Area (percent)*
66+	Excellent	11
56-65	Good	34
48-55	Medium	36
38-47	Poor	19

[1] Site index expresses forest site quality as the height of dominant trees in feet at the age of 50 years.

The paper birch forest type stands are in fairly good condition, as indicated by levels of desirable stocking and other conditions affecting current and prospective tree growth. Thus, 29 percent of the areas are at least 70-percent stocked with desirable trees. Another 44 percent are 40- to 70-percent stocked with desirable trees, and only 27 percent are less than 40-percent stocked with desirable trees.

More than half (54 percent) of the Minnesota paper birch forest type stands are in the 30-to 50-year age groups. Seven-eighths of the paper birch growing stock volume on all commercial forest land is in poletimber-size trees (5 to 10.9 inches d.b.h.).

[1] *Names and dates in parentheses refer to Literature cited.*

[2] *Defined roughly as forests in which quaking aspen, bigtooth aspen, or paper birch, or any combination of these species, comprises 50 percent or more of the stand.*

Table 1. — Paper birch growing stock[1] and sawtimber[2] on commercial forest land in the Lake States[3]

State	Net volume	Net annual growth	Annual desirable cut	Annual actual cut
		GROWING STOCK (Million cubic feet)		
Minnesota	768.5	28.0	19.7	2.5
Wisconsin	348.2	14.2	12.7	2.7
Michigan	438.0	20.6	14.9	2.4
Total	1,554.7	62.8	47.3	7.6
		SAWTIMBER (Million board feet)		
Minnesota	448.3	26.4	22.2	7.8
Wisconsin	188.0	16.9	8.4	3.0
Michigan	460.0	26.6	18.5	6.3
Total	1,096.3	69.9	49.1	17.1

1/ All live merchantable trees 5.0 inches d.b.h. (diameter breast height) and larger; volume measured from stump to a minimum 4-inch top diameter outside bark.

2/ All live trees at least 11 inches d.b.h. containing at least one merchantable saw log; volume measured from stump to a minimum 8-inch top diameter outside bark; International ¼-inch rule.

3/ From Findell et al. 1960, Stone and Thorne 1961, Stone 1966.

Contrary to the overall Lake States trend, Minnesota shows a decreasing trend in annual paper birch cut, possibly because of declining use as fuelwood: 4.7 million cubic feet were cut for all purposes in 1936, 3.5 million in 1953, and 2.5 million in 1960, all from growing stock on commercial forest land.

Even though the annual mortality is as high as 4 million cubic feet, the paper birch growing stock volume in Minnesota has increased from 416 million cubic feet in 1953 to 768 million in 1962. Most of this paper birch resource is in the north central and northeastern sections of the State.

Climate, Soils, and Associated Trees

Paper birch grows in a climate characterized by short cool summers and long cold winters with long periods of snow on the ground (Fowells 1965). This species has many varieties and hybrids which, as a group, have a transcontinental range from Alaska through most of Canada, the Lake States, and New England to New York.

It grows on a variety of soils over a wide range of soil-moisture conditions either in pure stands or, more often, as part of a mixed species stand. In the Lake States, paper birch is commonly found associated with aspen, jack pine, balsam fir, and white spruce (Findell *et al.* 1960, Stone and Thorne 1961, Stone 1966).

Paper birch, being intolerant of shade, usually lasts only one generation in the natural succession, and is then replaced by more tolerant species (Fowells 1965). In the northern Lake States, however, it is a common component of the climax white spruce-balsam fir-paper birch forest type, possibly due to its ability to occupy bare areas such as those created by blowdowns in the stands.

Reproduction and Growth

Reproduction is mostly from seed although moderate stump sprouting can occur (Gilbert and Jensen 1958) especially after cutting or fire (Fowells 1965). The newly germinated seedlings are very fragile, and are sensitive to moisture, light, and seedbed conditions. Seedlings as well as the older trees require overhead light. The growth rate is high — many individual trees have a diameter of 8 inches after 30 years (Betts 1945). However, this species has a short life span.

Trees on poorer sites, site index 40, should be cut at the age of 60 years in Wisconsin (Cooley 1962) when the trees have reached a height of 44 feet. On the better sites, site index 80, cutting can be delayed until the age of 80 years when the trees may be more than 100 feet tall and 14 inches or more in d.b.h. Trees in mature stands on intermediate sites average 10 inches in diameter and 70 feet in height (Fowells 1965). If cutting is delayed beyond the recommended ages, the growth rate soon becomes negligible and the wood deteriorates rapidly due to attacks by many enemies.

Enemies

A number of enemies can attack the tree. Stain fungi such as *Torula ligniperda* can cause red heart, which is characterized by wetwood (Campbell and Davidson 1941). Red heart affects 15 to 30 percent of the trees in mature stands (Brown *et al.* 1949). False tinder fungus, *Fomes igniarius*, and a clinker fungus, *Poria obliqua*, are the two most important rot-causing fungi that attack this tree (Fowells 1965). Discoloration and decay-causing organisms are frequently found together and interact (Shigo 1965).

Dieback, progressive dying from the treetop downward, is frequently seen in paper birch. This condition has been studied by a number of researchers. Dieback has coincided with a series of exceptionally dry summers and cold winters (Nash 1949), periods of high temperature and drought (Lortie *et al.* 1962), changes in chemical components in leaves (Lortie and Laforte 1962), fungi (U.S. NE Forest Exp. Sta. 1952), virus symptoms (Berbee 1957), and rootlet mortality (Greenidge 1953, Pomerleau and Lortie 1956). Cause-and-effect relations have been hard to prove, however. Tree injection experiments showed that three common elements of nitrogen, potassium, and phosphorus are not factors in occurrence of dieback (Morris 1951). No fungus or virus has ever been positively associated with birch dieback (Hahn and Eno 1956). Effects of dieback on the chemical properties of wood are not apparent (Timell 1957).

The bronze birch borer, *Agrilus anxius*, is often associated with dieback (Balch and Prebble 1940), and the borer may then cause the death of a tree that otherwise might have recovered (Barter 1957). Its attack usually begins in the crown and progresses downward into the bole as meandering galleries on

the surface of wood and in the outer layers of sapwood (MacAloney and Ewan 1964).

The forest tent caterpillar, *Malacosoma disstria*, can cause serious damage, especially if attacks are repeated. Annual growth may be reduced by as much as 86 per cent during the third year of complete defoliation (Barter and Cameron 1955).

Many animals damage this tree. Mice kill young seedlings by girdling (Stoeckeler 1955). Squirrels peel off the bark (Lutz 1956), and deer browse the leaves (Aldous 1952, Graham 1958).

A condition known as post-logging decadence often develops where the trees have been suddenly exposed by opening of the stands (Fowells 1965, Gilbert and Jensen 1958). The result is lowered vigor, reduced growth, dying back of twigs and branches, and sometimes even death of the tree.

Wood Quality and Properties

Paper birch wood has a fine even texture and uniform grain (U.S. Forest Prod. Lab. 1963). The wood cannot be separated with certainty from that of the other birches on the basis of either gross structure or minute anatomy (Panshin *et al.* 1964). The sapwood is white and 2 to 4 inches thick in mature trees, and frequently makes up nearly all of the wood in rapidly grown trees up to 10 inches in diameter (Betts 1945). The heartwood is light reddish brown (U.S. Forest Prod. Lab. 1963). Wood around the pith is often discolored and contains small checks, shakes, and pin knots; such wood is known as "heart center." Growth rings are frequently hard to see without a lens (Panshin *et al.* 1964). Wood is diffuse-porous. The larger pores are wider than the widest rays, and the pores are solitary or in multiples of two to several. The rays are so fine that they are often not visible to the naked eye. As in most hardwoods, fiber tracheids are short, 1.35 mm. long with a standard deviation of 0.15 mm.; and the vessel elements are 1.00 mm. long with a standard deviation of 0.26 mm. (Panshin *et al.* 1964).

Paper birch is moderately heavy (see specific gravity, table 2) when compared to all woods grown in the United States (Markwardt *et al.* 1961); yet it is generally lighter than either yellow or sweet birch (Panshin *et al.* 1964).

Physical and mechanical properties of paper birch (table 2) occupy intermediate positions in the ranges of properties of commercially important woods grown in the United States. Paper birch is moderately strong in bending strength and has moderate stiffness and moderate weakness in compression, but large shrinkage and high shock resistance (Markwardt *et al.* 1961). The wood's light color and almost complete lack of odor or taste make paper birch desirable for many uses.

The wood is fairly easy to dry. Even in Alaska, the 4/4-inch lumber can be air-dried in one summer down to 25-percent moisture content (U.S. Forest Prod. Lab. 1963), and sapwood 1-inch turning squares can be kiln dried down to 10-percent moisture content in 2½ days (U.S. Forest Prod. Lab. 1956).

Workability has been variously rated as relatively easy with handtools (U.S. Forest Prod. Lab. 1955), and as average with no reference to tools (Markwardt and Wilson 1935). Planing and shaping properties are fair (Davis 1962). In spite of many woods being noticeably better in turning qualities, paper birch turns well enough to be used commercially in large volume.

In assembly by nailing, nail splitting can be a problem; but once nailed without splitting, the nail-holding ability of this wood is high (U.S. Forest Prod. Lab. 1963). Gluing difficulties have been variously estimated, ranging from "glues well" (Panshin *et al.* 1964) to "difficult to glue" (U.S. Forest Prod. Lab. 1963).

The wood stains and finishes satisfactorily (U.S. Forest Prod. Lab. 1963). Once the product is finished, its ability to "stay in place" during moisture changes in normal use without warping has been variously rated as poorer than average (Markwardt and Wilson 1935) to good (U.S. Forest Prod. Lab. 1963).

Table 2. — Physical and mechanical properties of paper birch at various locations (Markwardt and Wilson 1935, Kennedy 1965)

Test and property	Unit of measure	Place of growth of material tested					
		Wisconsin		New Hampshire		Canada	
		Green	Dry	Green	Dry	Green	Dry
Moisture content at test	percent	72.0	4.2	58.7	11.8	--	12
Specific gravity, weight oven-dry volume at test		0.473	0.582	0.494	0.568	0.506	0.571
Static bending							
Stress at proportional limit	p.s.i.	2,920	11,440	3,020	7,330	3,200	7,430
Modulus of rupture	p.s.i.	5,770	16,050	7,000	14,060	6,850	13,750
Modulus of elasticity	1,000 p.s.i.	1,013	1,814	1,328	1,744	1,450	1,870
Work to proportional limit	in.-lb. per cu. in.	0.49	4.32	0.40	1.85	0.40	1.67
Work to maximum load	in.-lb. per cu. in.	15.0	13.2	17.4	18.2	14.6	20.7
Impact bending, height of drop causing complete failure (50-pound hammer)	in.	45	24	53	48	42	47
Compression parallel to grain							
Stress at proportional limit	p.s.i.	1,640	6,140	1,630	3,620	1,670	3,710
Maximum crushing strength	p.s.i.	2,210	9,470	2,510	6,140	2,690	6,480
Compression perpendicular to grain, stress at proportional limit	p.s.i.	304	912	370	1,002	358	997
Shear parallel to grain, maximum shearing strength	p.s.i.	786	1,627	886	1,214	944	1,634
Tension perpendicular to grain, maximum tensile strength	p.s.i.	382	--	--	--	618	1,040
Hardness--load required to embed a 0.444-in. ball to ½ its diameter							
End	lb.	400	1,487	532	928	562	979
Side	lb.	486	1,278	632	996	620	972
Shrinkage from green to oven-dry condition based on green dimensions							
Volumetric	percent	16.3	--	16.0	--	13.8	--
Radial	percent	6.6	--	6.0	--	5.2	--
Tangential	percent	8.8	--	8.5	--	7.2	--

Chemical analysis of the wood reveals the following components (U.S. Forest Prod. Lab. 1963):

	Percent
Lignin	19.0
Holocellulose	77.0
Alpha cellulose	45.0
Total pentosans	23.3

	Percent
Solubility in —	
Alcohol benzene	2.8
Ethyl ether	1.3
1-percent NaOH	14.1
Hot water	1.5

Paper birch has a higher holocellulose and a lower lignin content than most other native species.

Uses

The United States as a whole cuts half of its wood into saw logs, a quarter into pulpwood, and one-tenth into fuelwood (U.S. Forest Service 1965). The Lake States reverses the saw log and pulpwood proportions — nearly half of its wood goes for pulpwood, almost a quarter for saw logs, and a quarter for fuelwood.

Data for Michigan in 1965 shows paper birch used in yet another proportion — half still is pulpwood, but fuelwood use at 30 percent is higher than saw log use at 16 percent.[3] Veneer logs at 3 percent are in fourth place, with miscellaneous industrial products making up the remaining 1 percent. These use ratios reflect the small size of paper birch in the Lake States.

Pulpwood

Pulpwood is the most substantial use for paper birch in the Lake States; in 1965 pulpwood production was 55,359 cords (Horn 1966).

Use of paper birch as pulpwood is increasing in Wisconsin and Michigan, but not in Minnesota. This may be due to the fact that local supplies of the traditional pulpwood species have been depleted in Wisconsin and some parts of Michigan whereas Minnesota mills still have greater quantities of these species within easy reach.

Sticks as small as 4 inches inside bark at the small end are often acceptable if otherwise of sound quality (Davis 1953). Sticks are commonly 100 inches long. However, depending on the method of transportation, pulpwood can be delivered either in cordwood lengths of 4 to 8 feet, in log lengths of 12 to 24 feet, or in tree lengths (Panshin *et al.* 1962). Paper birch lasts in storage as well as aspen or balsam, but not as well as hemlock or spruce. It must usually be pulped within a year to avoid deterioration (Davis 1953).

Groundwood paper birch pulp has a low strength but a fair color (Hyttinen and Schafer 1948). Up to 25 percent of this pulp can be used in toweling and 30 percent in newsprint (Schafer and Pew 1942). It can also be used as filler stock in book papers (U.S. Forest Prod. Lab. 1963). Groundwood pulp yields are typically very high, about 93 percent by weight.

Chemigroundwood paper birch pulp is moderately low in strength and is usually blended with softwood groundwood and sulfite pulps to make newsprint paper (U.S. Forest Prod. Lab. 1963). Chemiground pulp yield varies between 80 and 95 percent by weight.

Chemimechanical cold soda paper birch pulp is comparatively low in strength, but has its use in mixtures with other pulps for box boards and book and newsprint papers (U.S. Forest Prod. Lab. 1963). Cold soda pulp yield varies between 80 and 95 percent by weight.

Neutral sulfite semichemical paper birch pulp is particularly bright and strong (U.S. Forest Prod. Lab. 1963). It is used in corrugating and coarse wrapping paper furnishes (Tech. Assoc. Pulp Pap. Ind. 1947), and it has been found to produce lithographic paper of good quality (U.S. Forest Prod. Lab. 1963). It has use as a substitute for chemical pulps in newsprint and other groundwood-sulfite papers. Newsprint paper has been made at the Forest Products Laboratory using 20 to 60 percent birch sulfite semichemical pulp together with varying amounts of spruce and birch groundwood. Semichemical pulp yield varies between 60 and 80 percent by weight.

Sulfate paper birch pulp seems to have the best overall strengths properties of any hardwoods (U.S. Forest Prod. Lab. 1963). It reduces readily with high yield and a strength equivalent to 75 percent of spruce pulp strength (Isenberg 1951). Finnish birch, a close relative of paper birch, is used to make sulfate pulp that competes with coniferous wood sulfite pulps in strength and is even more important in providing bulk, opacity, compressibility, smoothness, and absorption power to paper when used in mixtures with coniferous wood pulps (Alm

[3] *Personal communication from J. E. Blyth, North Central Forest Experiment Station, 1968.*

1965). The paper birch sulfate pulp yield is 50 percent by weight (U.S. Forest Prod. Lab. 1953).

Sulfite paper birch pulp strength is almost equal to the strength of hemlock pulp, and is about 75 percent as strong in burst and 90 percent in tear as spruce sulfite (Tech. Assoc. Pulp Pap. Ind. 1947). Seasoned paper birch is preferred over green wood to avoid trouble caused by wax in the wood (Isenberg 1951). The wood reduces easily, with a normal yield of rather poor-colored pulp that, however, is easy to bleach (U.S. Forest Prod. Lab. 1963). The yield is 46 percent by weight (U.S. Forest Prod. Lab. 1953).

Chemical soda pulp can be made from paper birch also, and is fairly easy to bleach (Isenberg 1951). But it reduces with some difficulty (U.S. Forest Prod. Lab. 1963). The pulp yield is normal. (Isenberg 1951), 42 percent by weight (U.S. Forest Prod. Lab. 1953).

Thus, paper birch can be pulped by any process, and various types of papers can be made. Producers, however, usually prefer to deal with other species of trees that are easier to handle and peel (Davis 1953). When paper birch is used, it is typically mixed with other woods to make up the short-fiber content of paper.

Consumption of paper and board is increasing rapidly, with a projected demand for pulpwood by the year 2000 nearly triple that of 1962 (U.S. Forest Serv. 1965). Hardwoods are expected to make up an increasingly larger share of the pulpwood, with a projected 40-percent share of the total round pulpwood by the year 2000. The largest increase in demand is expected for sulfate and semichemical pulps, both processes for which paper birch is well suited. Thus, greater demand for paper birch pulpwood can be foreseen.

Fuelwood

Fuelwood is the second most important use group for small-sized paper birch. One of the advantages of dry wood as a fuel is that it ignites readily and gives a quick, hot flame (Panshin *et al,* 1962). Paper birch has these characteristics to a high degree due to the nature of its bark structure and high heat value. In addition, paper birch sticks are attractive, and consequently they find use in the limited market of luxury fireplace wood.

Although the demand for fuelwood is still substantial, it is declining (U.S. Forest Serv. 1965). During recent decades oil, gas, coal, and electricity have been increasingly substituted for wood, both for home cooking and heating and for industrial uses.

Saw Logs

The larger paper birch trees are cut into saw logs and veneer logs. Several years ago the principal paper birch lumber source in the northern Lake States was the so-called "side lumber," a byproduct of crosstie manufacture (Davis 1953). Today this source is less important, and lumber is a primary product cut from the log. In Vermont, a large portion of the ungraded hardwood lumber is paper birch; it is sawed "through and through" and sold round edge (Whitmore 1962). The lumber is used for boxes and crates (U.S. Forest Prod. Lab. 1963), pallets, picket fencing, knotty paneling (Davis 1953), and so on.

Lumber used in containers has dropped substantially in recent years, largely because nailed, lock-corner, and wirebound boxes have been displaced by corrugated and other fiber boxes, metal and fiber drums, and multiwall paper bags (U.S. Forest Serv. 1965). However, use of wood for pallets is growing steadily. A substantial rise is also projected in total use of lumber and panel products in construction. Paper birch is good for pallets and panel products.

Veneer Logs

The best quality, large-size paper birch trees can be cut into veneer logs. Until recently veneer logs have had to meet strict quality standards as to size. All general veneer grade logs have had to be at least 12 inches in diameter and at least 8 feet 6 inches in length (Peterson 1965). However, new lathes with supporter rolls, and chucks with changeable spindles have made it possible to cut logs down to 3- or 4-inch cores, so that smaller diameter logs can now be used.

Saks (1951) has suggested that since the most popular sizes turned out by the veneer and plywood industry are 7-foot and 8-foot panels, log lengths to produce such panels should be 7 feet 6 inches and 8 feet 6 inches. The standard veneer is used to make plywood, furniture (U.S. Forest Prod. Lab. 1963), cabinets, and school seating (Davis 1953) among others. Paper birch is suited for these products.

Specialty veneer products form an interesting group. Smaller segments of the tree can often be used for these products than for standard veneer products. For example, wooden match box cover veneer can be made of 100-inch paper birch bolts with a diameter of 8 inches or more at the small end inside bark. Some specialty veneer products manufacturers even accept bolts 6 inches in diameter and 50 inches in length (Davis 1953). Other specialty veneer items include round cheeseboxes, and die-cut products (fig. 1). Paper birch is a preferred species for die-cut products such as ice-cream sticks, picnic

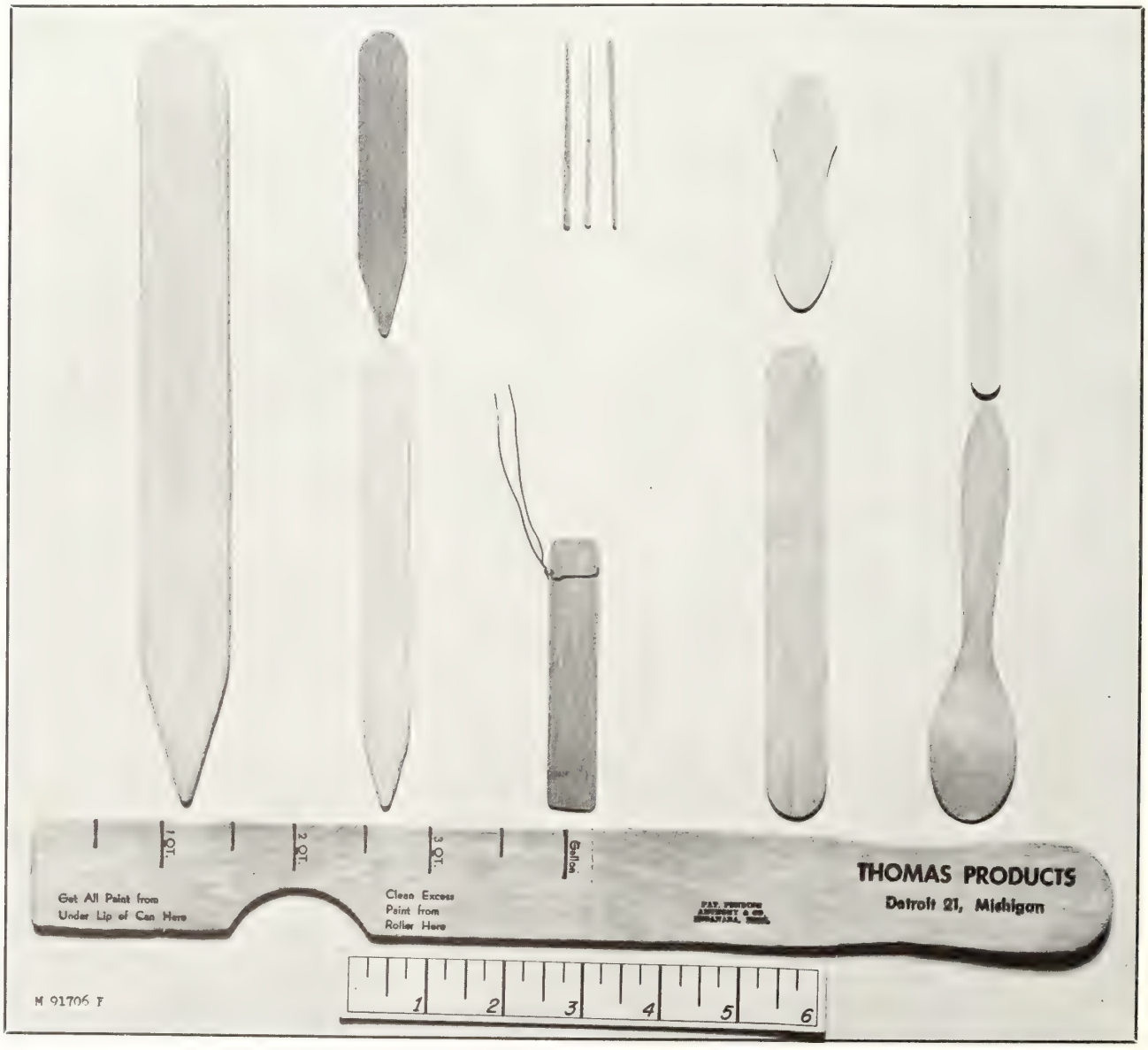

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FIGURE 1. — Typical die-cut products made from rotary veneer of paper birch.

spoons plant markers, swab slats, tongue depressors, and toothpicks.

The value of hardwood logs required to meet projected demands in the year 2000 for hardwood veneer and plywood is estimated at 3.3 times that of the year 1962 (U.S. Forest Serv. 1965).

Turning Products

A considerable quantity of paper birch is used for miscellaneous turning products in the northern Lake States, but even more is used for that purpose in New England. Maine, New Hampshire, and Vermont, the best paper birch area, have more wood-turning plants than all other states combined (Panshin *et al.* 1962). Bolts 50 and 100 inches long and down to 6 inches in diameter are acceptable if they are sound, smooth, and straight (Davis 1953). Turning products (fig. 2) include bobbins, clothes pins, and spools (U.S. Forest Prod. Lab. 1963); broom handles, chair rounds, dowels, mop handles, and shuttles (Davis 1953); and shoe pegs and shoe shanks (Betts 1945).

Crossties

Until recently small quantities of paper birch have been used by portable mills in the northern Lake States for making crossties (Davis 1953). Logs with a 9-inch minimum diameter and an 8-foot length are required (Peterson 1965). These ties, class T, have to be treated with preservative (Panshin *et al.* 1964).

Other Products

Other uses for paper birch include mine props in Alaska (U.S. Forest Prod. Lab. 1963), toys, and carved articles. The bark was used by northern Indians for canoes and even today various small articles are made from the bark. At least one mill in the Lake States has used paper birch in the manufacture of particleboard.

Prices

A knowledge of prices is essential to landowners and managers in their timing and choice of products to be harvested. The buyer, too, must know the latest prices of such products in his area and must consider his own costs as well as the price he will receive for his finished product such as lumber. Prices of saw logs, lumber, and so on vary considerably by locality and with time, and therefore offer an opportunity for profit as well as the chance of a loss.

Paper birch veneer logs bring the highest prices, but require best quality large-size trees. Paper birch veneer log prices span the gap between the higher yellow birch prices and the lower aspen prices in Minnesota. Paper birch pulpwood prices, on the other hand, have in the past been only about half as high as spruce pulpwood prices and only slightly higher than aspen pulpwood prices. Paper birch saw logs are next highest to veneer logs in price.

Some Recommendations for Additional Research

The use of any one species such as paper birch for a product depends on its availability in needed quantities, the costs of production, and its suitability for the product compared to other woods and substitute material. Further research should be conducted with these points in mind.

The existence now or in the near future of large sawtimber-size stands could be studied. Do we now have such stands in sufficient quantity in some as yet untapped region, or will they be created by ingrowth soon, to justify expanded veneer and saw log operations?

The economic aspects of pulping paper birch by various processes have not been nearly as fully reported in the literature as the technical aspects and should be studied.

FPL No. M 91480 F

FIGURE 2. — Some types of small turnings made from paper birch in New England.

Lumber quality of sawtimber-size paper birch trees is another subject about which not enough is known.

Fiber and particleboard industries are potential users of the poletimber-size stands as well as some of the sawtimber-size stands. This use should be investigated, especially for paper birch mixed with aspen with which it frequently forms mixed stands over much of its range. Use of paper birch with its bark in insulation board and particleboard could also be explored.

Additional investigation is needed on controversial points concerning the quality and properties of paper birch wood, particularly its workability, gluing characteristics, and ability to stay in place.

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Acknowledgements

The Eighth Lake States Forest Tree Improvement Conference, held at Madison, Wisconsin, on September 12-13, 1967, was an opportunity for tree breeders and forest genetics research workers representing Universities and private, State, and Federal organizations to exchange knowledge formally and informally.

The Forest Products Laboratory of the U.S. Forest Service was host. Program arrangements were the joint responsibility of Dean W. Einspahr, Institute of Paper Chemistry, Appleton, (Program Chairman and Vice Chairman of the Lake States Forest Tree Improvement Committee); Donald T. Lester, Department of Forestry, University of Wisconsin; and Harold L. Mitchell, Forest Products Laboratory.

During the first day, papers were formally presented. On the second day a guided tour was made through the Forest Products Laboratory, the University of Wisconsin Department of Forestry greenhouses, and the University outplanting sites in the vicinity of Madison. The meeting also provided the time and facilities for a meeting of the Tree Improvement Committee (NC-51) of the North Central Land Grant Colleges.

The Tree Improvement Committee wishes to thank the North Central Forest Experiment Station of the U.S. Forest Service for publishing these proceedings. The Committee also wishes to thank all individuals who contributed to the Conference, the men responsible for the organization and arrangement of the meeting, and the scientists who presented papers. Our special thanks go to Dr. Earl P. Stephens, Director of Forest Research, U.S. Plywood-Champion Papers, Inc., who presented a stimulating invited paper during the meeting. Dr. Stephens lectured on "Growing Cottonwood . . . Texas Style" without a manuscript. It has, therefore, not been possible to include his comments in the Proceedings.

J. W. Wright, Chairman
Lake States Tree Improvement Committee

Proceedings of the Eighth Lake States Forest Tree Improvement Conference, September 12-13, 1967

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VARIATION IN HEIGHT GROWTH AND GROWTH CESSATION OF 55 YELLOW BIRCH SEED SOURCES

Knud E. Clausen[1]

Yellow birch (*Betula alleghaniensis* Britt.) is an important hardwood species in the Lake States, northeastern United States, and eastern Canada. Since it produces valuable timber, the species is a logical candidate for genetic improvement. An understanding of the variation pattern in a species is, however, basic to any improvement program.

In 1963 the Institute of Forest Genetics, Rhinelander, Wisconsin, initiated a study of natural variation in yellow birch. This paper describes variation in height growth and growth cessation in 2-year-old seedlings grown from the material collected for this study.

Methods

Seed was collected in 1963 and 1964 with the generous assistance of many cooperators in the United States and Canada. Most of the 55 sources used in the study (fig. 1, table 1) include seed of 10 or more trees per stand. Exceptions are sources 3068, 2958, 2996, and 3001 which represent seed of one, four, eight, and eight trees, respectively.

On March 24-26, 1965, three seed lots of each source were sown in flats and covered with moist peat. The flats were kept at 35° F. in a cooler for 4 weeks and then moved to a lathhouse. When germination was complete the seedlings were given supplementary light and grown under long days (18 hours) until transplanted. The seedlings were transplanted into four randomized complete blocks in the Hugo Sauer Nursery at Rhinelander on July 22-28, 1965.

Height growth of 20 seedlings in each plot was measured at the end of the first and second growing season. First-year height is probably confounded with the long-day treatment and the effects of the transplanting; hence only second-year height growth is considered here. To determine when the plants stopped growing during the second year height growth of five seedlings per plot was measured weekly from July 6, 1966, until shoot elongation had ceased.

Results and Discussion

The average hight growth of the 55 seed sources during their second year was 122.3 mm, but the individual sources varied from a low of 86.1 mm to a high of 164.0 mm (table 1). Thus, the West Virginia source (2969) and the Lower Michigan source (2961) grew almost twice as much as Nova Scotia source 3065, which was poorest. All but four sources performed better than the local source (3298). The differences between the sources were highly significant (table 2), but much block variation was also present. The best block, for example, averaged 43 percent more height growth than the poorest one. The differences between the blocks appear to be partially related to their relative proximity to a windbreak, but may also be due to soil differences or other environmental factors.

The seed sources stopped growing an average of 7.2 weeks after July 6, the date of the first measurement, but individual sources varied greatly in time of growth cessation. Source 3243 from eastern Newfoundland ceased growth one week earlier than the average, while the Kentucky source (3294) remained active 1½ weeks later than the average (table 1). Thus, growth cessation of the sources took place over a period of about 2½ weeks or from about August 11 to August 28. The 14 sources which ceased growth at the same time as, or later than, the local source (3298) were all of more southerly origin than the local source. The differences between the sources were highly significant (table 2), and again there was significant variation between the blocks.

Correlation analyses showed that height growth of 2-year-old seedlings is apparently not correlated with latitude, longitude, length of growing season, annual precipitation, and average July temperature of the seed sources; furthermore, height growth appears to vary in a random manner. Although some of the variation between the sources seems to be due to differences in growth rate, these differences do not follow any consistent geographic pattern. Second-year height growth is also uncorrelated with growth cessation, and surprisingly, with first-year height. Whether the pattern of variation in height growth of yellow birch is actually random should become apparent with future measurements.

Growth cessation, on the other hand, is inversely correlated with latitude, directly correlated with average July temperature, weakly correlated with length of growing season and annual precipitation, and independent of longitude (table 3). Generally speaking, northern sources stopped growing earlier than southern sources, indicating photoperiodic control of growth cessation. This result agrees with previous work by Wang and Perry (1958) who reported that photoperiod controlled cessation of shoot elongation in yellow birch and paper birch (*Betula papyrifera* Marsh.).

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Table 1. — Origin, mean second-year height growth, and mean growth cessation of 55 yellow birch seed sources

Source no.	State or province	Degrees of-- Lat.	Degrees of-- Long.	Elevation (ft.)	Growing season (days)	Height growth (mm)	Growth cessation[1/]
3243	Newfoundland	47.2	53.4	50	110	117.9	6.15
3244	"	48.6	58.2	400	110	135.0	6.50
3241	Nova Scotia	46.6	60.5	100	120	146.0	7.10
3065	"	45.4	61.8	450	102	86.1	7.20
3242	"	44.8	65.2	650	130	117.8	7.05
3063	"	44.1	65.8	350	140	101.2	7.65
3068	New Brunswick	46.0	66.4	300	126	146.4	7.30
3066	"	47.4	65.2	300	130	131.4	6.85
3067	"	47.5	67.4	925	70	131.8	6.45
3001	Province of Quebec	49.2	65.1	300	135	95.6	6.25
2998	"	48.2	70.2	1000	107	108.4	6.40
2997	"	47.0	70.3	400	120	100.8	6.80
2999	"	47.4	72.6	1000	107	124.1	6.95
3000	"	47.5	75.0	1500	90	104.0	6.60
3002	Ontario	45.1	76.9	1000	115	136.3	7.20
3003	"	46.1	79.0	1000	115	117.2	6.95
3004	"	46.7	79.6	1000	115	119.8	6.95
3311	"	45.0	81.4	625	145	139.6	7.25
3309	"	47.5	84.8	1000	110	118.4	6.75
2977	Maine	44.8	68.6	250	142	109.8	7.30
2956	"	43.7	70.9	1000	130	96.5	7.25
2985	New Hampshire	44.0	71.4	1900	125	101.6	7.00
2986	"	43.5	71.4	1300	130	145.4	7.60
2982	Vermont	44.7	72.6	1250	115	124.5	7.25
2971	Massachusetts	42.7	73.2	1610	150	116.4	7.35
2980	New York	49.2	74.9	1620	111	130.6	7.40
2996	"	42.5	74.2	2100	135	129.4	7.35
2976	"	42.3	77.3	1300	145	150.6	7.75
2979	Pennsylvania	41.3	76.3	2300	150	132.3	7.35
3312	"	41.6	78.7	1800	120	158.4	7.75
2969	West Virginia	39.0	79.7	2200	145	164.0	8.15
3299	Virginia	37.8	79.1	3000	175	111.7	7.65
2959	North Carolina	35.7	82.3	5160	135	134.1	7.90
2973	Georgia	34.8	83.8	4700	185	111.2	7.35
2953	Tennessee	35.2	85.7	1740	180	115.0	7.90
2954	"	35.7	85.3	1420	185	90.2	7.50
3294	Kentucky	36.9	82.9	3600	180	142.5	8.55
2955	Ohio	39.5	82.5	830	165	131.0	7.65
2958	Indiana	38.3	86.5	700	165	118.7	7.35
2983	Illinois	41.9	89.4	680	164	112.3	7.45
3295	Iowa	42.4	93.1	1050	150	151.1	7.30
2961	Michigan	45.0	85.0	1000	110	163.8	7.55
2960	"	45.9	84.8	625	140	126.6	6.90
2978	"	46.7	87.9	1675	110	130.2	6.60
2987	"	47.0	88.7	1250	140	108.3	6.90
2968	Wisconsin	46.5	92.1	1150	140	123.6	6.80
3298	"	45.7	89.0	1710	110	96.1	7.45
3297	"	44.5	90.4	1100	130	125.1	7.50
2962	"	44.9	87.2	600	145	130.4	7.30
2963	"	43.1	88.4	900	165	114.0	7.00
2964	Minnesota	44.2	94.1	800	150	95.4	6.90
2965	"	47.2	95.2	1480	100	127.6	7.00
2966	"	47.6	92.5	1700	110	122.0	6.75
2967	"	47.8	90.2	1400	130	107.6	6.60
2957	Isle Royale, Michigan	47.9	89.1	750	120	101.2	6.65

1/ In weeks after date of first measurement, July 6, 1966.

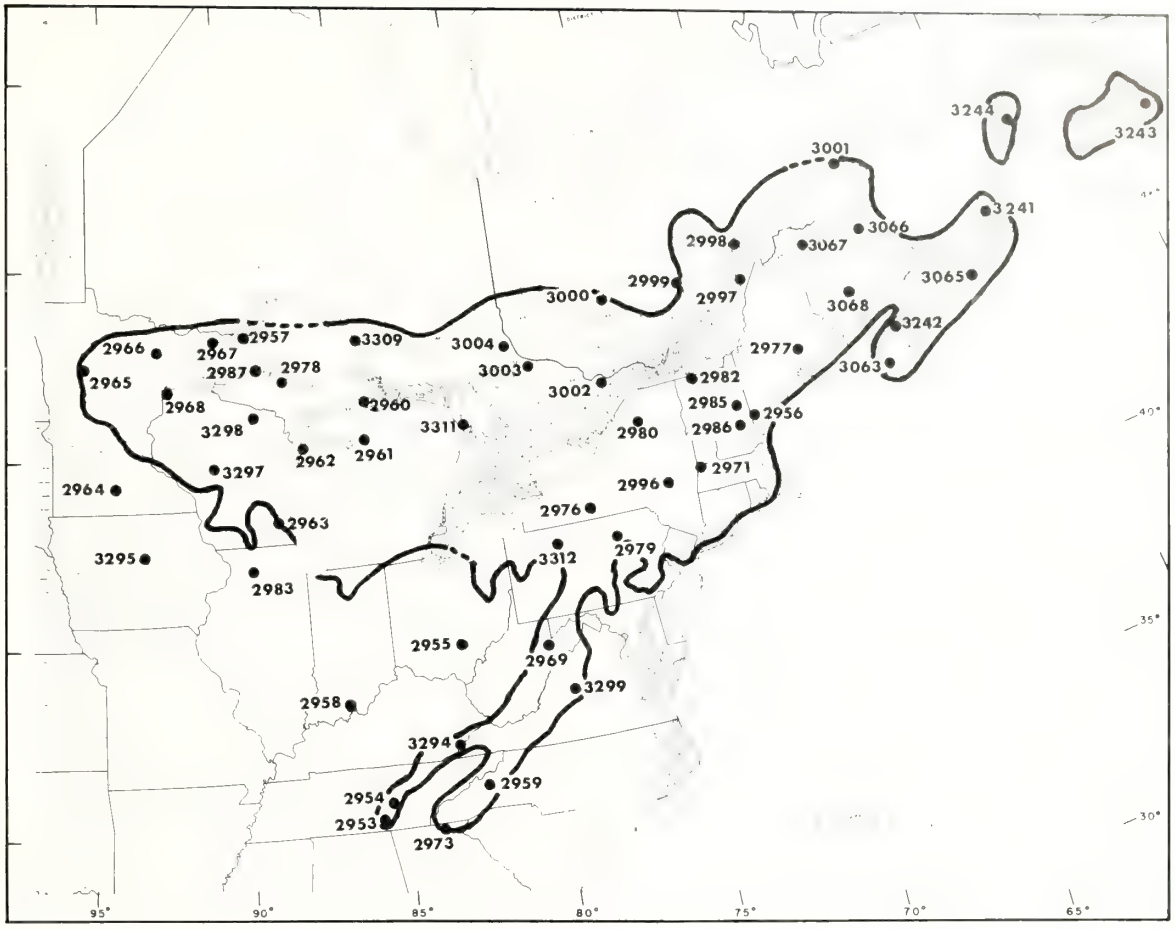

FIGURE 1. — Natural range of yellow birch adapted from maps in Fowells (1965) and Dansereau and Pageau (1966) and location of seed sources.

Table 2. — Analysis of variance of height growth and growth cessation of 55 yellow birch seed sources[1]

Source of variation	Degrees of freedom	Variance ratio (F) Height growth	Growth cessation
Blocks	3	34.39**	29.13**
Sources	54	2.53**	2.21**
Error	162	--	

1/ The analysis is based on plot means.

** Significant at the 1-percent level.

Table 3. — Correlation between height growth and growth cessation of 55 yellow birch seed sources and environmental variables of the seed sources

Environmental variable	Height growth	Growth cessation
Latitude	-.1206	-.7824**
Longitude	.0176	.2157
Length of growing season	-.0523	.5606**
Annual precipitation	.0704	.5168**
Average July temperature	.1031	.6274**

Conclusion

This study provides no evidence of clinal variation in height growth of yellow birch. On the other hand, certain seed sources grew much better or worse than others during the second year in the nursery; it would, however, be premature to consider them ecotypes. Since variation in height growth appears to be random over the natural range of this species, the amount of variation present within more limited geographic areas should be considered. In the Lake States region, for example, the difference between the best and the poorest seed sources was 34 percent for Minnesota, 36 percent for Wisconsin, and 52 percent for Michigan. When the 14 Lake States sources are compared as a group, the southern Minnesota source (2964) is 20 percent shorter and the Lower Michigan source (2961) 37 percent taller than the Lake States average. Thus, much potential growth may be lost if a slow-growing seed source is used for reforestation purposes. More intensive studies of local variation may be necessary in order to determine the pattern of variation associated with environment and to locate the fastest growing seed sources. Yellow birch exhibits much within-stand variation in fruiting characteristics (Clausen, 1967). If a similar pattern is present in growth characteristics, it is probable that certain trees will produce much faster growing progeny than others.

In contrast to the random variation observed in height growth, the study demonstrates that yellow birch exhibits clinal variation in growth cessation. This process is probably controlled to a high degree by photoperiod as it is in many other woody plants.

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SEED SOURCE VARIATION IN TRACHEID LENGTH AND SPECIFIC GRAVITY OF FIVE-YEAR-OLD JACK PINE SEEDLINGS

James P. King[1]

Jack pine (*Pinus banksiana* Lamb.) is widely used in Lake States reforestation because of its ability to make rapid early growth on relatively infertile sites. It is a major pulpwood producing species. Since the quality and yield of pulp are so strongly influenced by tracheid length and specific gravity, information on genetic variation in these characteristics would be useful in planning future jack pine tree improvement programs.

This study was done to: 1) measure tracheid length and specific gravity variation by seed source in the juvenile wood of jack pine; and 2) develop a basis for comparing wood quality variation by seed source in young seedlings with that in mature trees.

Material and Methods

A jack pine seed source test was established in the Hugo Sauer Nursery near Rhinelander, Wisconsin, in spring 1962. This test was initiated by Mr. M. Holst of the Petawawa Forest Experiment Station, Chalk River, Ontario, Canada. He arranged for the collection of seed from 100 natural jack pine stands located over the entire range of the species. The seed collections were distributed among a number of cooperators in Canada and the United States. Ninety-two of the collections are represented in the Rhinelander planting.

The seed was sown in a 5-replicate randomized complete block design. Ten contiguous seed spots of each source are contained in each replication. Each spot was randomly thinned to three seedlings at the beginning of the second growing season and to one seedling at the beginning of the third growing season. Chemical weed control, fertilization, and irrigation promoted vigorous growth.

At the end of the 1966 (fifth) growing season when the test was to be terminated, 34 sources were selected for measurements of tracheid length and specific gravity (fig. 1). For each source, 5 trees of each of the 5 replications were sampled; i.e., 25 trees per seed source or a total of 850 trees.

After considering concepts discussed by Richardson (1961) and Dinwoodie (1961), we decided that, to compare trees, wood samples must be taken at a common internode and common growth ring for all trees. Thus, all samples were taken from the center of the lowest 1964 internode (jack pine is multinodal). A piece of the main stem 3 to 5 centimeters long was cut from each tree and debarked. The entire cross-section (1964, 1965, and 1966 wood) was used for specific gravity determination, but only the outermost portion of the 1966 summerwood for tracheid length determination.

Specific gravity was computed as the ratio of ovendry weight to green volume (in metric units). Green volume was measured by the water-immersion method, and oven-dry weight was measured after drying the samples in a 105°C oven for 48 hours.

Small slivers were then chipped off around the outermost portion of the 1966 summerwood and put into vials containing equal volumes of 10-percent chromic acid and 10-percent nitric acid (Jeffrey's reagent). After about 26 hours, the macerated material was washed by decanting it several times with tap water. The tracheids were then mounted on temporary slides, and 30 to 40 whole tracheids per slide were measured by projecting the slides on a wall-mounted screen with a microprojector. Two of the replications were measured at magnifications of about 350 to 1; the other three at magnifications of 400 to 1. The magnification was recalibrated at least twice a day, and the microprojector was never moved unless an entire replication had been completed.

All the samples in this study were kept separate by nursery replicate. That is, the samples for an entire replicate were collected, weighed, dried, reweighed, macerated, and measured in random order before the next replicate was started. Thus, any variation due to experimental techniques would appear in analysis as between-replicate differences and would not seriously affect seed source comparisons.

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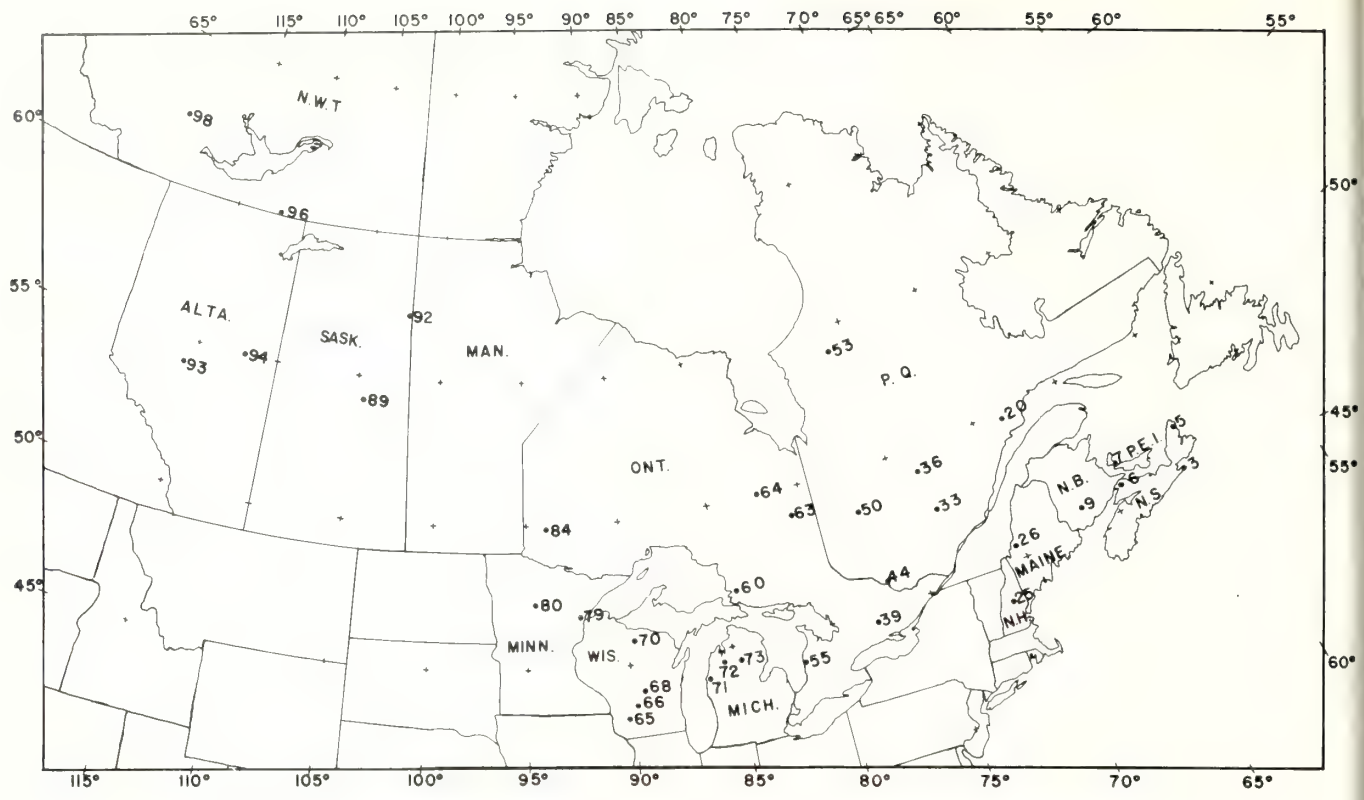

FIGURE 1. — Location of the 34 jack pine seed sources used in the measurement of tracheid length and specific gravity.

Results

There are real differences among seed sources in both tracheid length and specific gravity (tables 1 and 2). The mean tracheid length for all sources was 1.38 mm. The source from Fife Lake, Mich., had the longest tracheids; they averaged 1.62 mm — about 17 percent greater than the mean. The source from Reindeer Lake, Saskatchewan, had the shortest mean tracheid length — 1.12 mm or about 18 percent below the overall mean.

Considering only the nine seed sources from the Lake States, the mean tracheid length was 1.50 mm and ranged from 1.44 to 1.62 mm. The mean tracheid length for the Cloquet, Minnesota, source was 1.45 mm. This agrees well with a study by Kribs (1928) of natural-grown jack pine at Cloquet wherein the tracheid length of 3-year-old wood, one foot above the ground, averaged about 1.42 mm (interpolated from Krib's data).

The variation in specific gravity was less than that of tracheid length. Mean specific gravity for all sources was 0.350. The source at Reindeer Lake, Saskatchewan, had the highest specific gravity — 11 percent above the overall average — and the source at Fort Coulonge, P.Q., had the lowest — 8 percent below average. The average specific gravity of the nine Lake States sources was 0.339, and there were no significant differences between these seed sources.

In this material, strong positive correlations exist between mean seed source tracheid length, 1964 diameter inside bark, and 1964 shoot length (table 3). Strong negative correlations exist between mean seed source specific gravity and tracheid length, diameter inside bark in 1964, and 1964 shoot length.

Covariance analyses (table 4) indicated that seed source differences in tracheid length could not be entirely accounted for by variation in diameter inside bark or 1964 shoot length. Because of the high correlation between 1964 shoot length and the diameter inside bark, the effects of these two variables on tracheid length could not be evaluated independently. Specific gravity differences were also not entirely related to diameter and hence rate of growth.

In general, the more northerly sources had the slowest growth rate and therefore the highest

Table 1. — Mean tracheid length, specific gravity, 1964 shoot length, and 1964 shoot diameter inside bark of 34 jack pine seed sources

	Number and location	Tracheid length	Specific gravity	1964 shoot length[1/]	Diameter (inside bark)[2/]
		Mm		Cm	Mm
03	Durell Island, N.S.	1.13	.384	14.4	14.6
05	Neils Harbor, N.S.	1.17	.376	21.2	15.7
06	Thomson Station, N.S.	1.38	.338	31.2	21.6
07	East Bideford, P.E.I.	1.46	.339	29.6	21.5
09	Grand Lake, N.B.	1.35	.351	32.7	22.1
20	Toulnoustook River, P.Q.	1.38	.348	27.8	20.2
25	Welch Mt., N.H.	1.31	.349	31.1	21.7
26	Spencer Lake, Maine	1.41	.337	31.7	22.8
33	Lake Valade, P.Q.	1.39	.338	28.2	23.3
36	Ducharme River, P.Q.	1.38	.351	27.3	22.6
39	Twin Lakes, Ont.	1.46	.347	35.5	24.7
44	Fort Coulonge, P.Q.	1.47	.321	43.1	26.2
50	Lac Villebon, P.Q.	1.39	.345	26.6	22.6
53	Kanaaupscow Lake, P.Q.	1.19	.379	10.4	12.6
55	Clark Point, Ont.	1.46	.350	29.8	23.0
60	Goulais River, Ont.	1.44	.341	31.3	23.3
63	Nellie Lake, Ont.	1.41	.335	28.6	21.9
64	Smoky Falls, Ont.	1.35	.363	20.3	18.4
65	Lone Rock, Wis.	1.45	.337	45.6	27.6
66	Wisconsin Dells, Wis.	1.55	.337	46.9	26.9
68	Waupaca, Wis.	1.51	.334	48.6	27.4
70	Nokomis, Wis.	1.47	.341	42.5	24.8
71	Freesoil, Mich.	1.49	.341	44.7	26.9
72	Fife Lake, Mich.	1.62	.340	46.8	26.2
73	Marl Lake, Mich.	1.51	.337	45.1	25.7
79	Cloquet, Minn.	1.45	.338	42.0	25.4
80	Cass Lake, Minn.	1.47	.343	39.8	25.8
84	Vermillion Bay, Ont.	1.39	.345	32.7	23.1
89	Nipekamew River, Sask.	1.28	.366	19.2	17.4
92	Reindeer Lake, Sask.	1.12	.389	11.0	11.9
93	Whitecourt, Alta.	1.30	.361	19.1	18.5
94	Lac la Biche, Alta.	1.32	.354	21.4	19.3
96	Fort Smith, N.W.T.	1.18	.368	12.5	13.3
98	Fort Simpson, N.W.T.	1.13	.375	11.5	12.9
Mean		1.38	.350	30.3	21.5
$S_{\bar{x}}$		.036	.0052	2.70	1.09

1/ Measured in the nursery to the nearest centimeter.
2/ Measured to the nearest millimeter.

specific gravity and shortest tracheids. There was one notable exception: The two sources from eastern Novia Scotia — relatively low-latitude sources for jack pine — were among the slowest growing. Sources from Wisconsin and Michigan were among the fastest growing and seemed taller as a group than those from southern Ontario, New Brunswick, Quebec, and New England to the east. The data suggest several east-west discontinuities in the jack pine population, but this may be the result of the low number of widely spaced seed sources used in this investigation. Any conclusions regarding population structure of jack pine must await the analysis of the growth data for all 92 sources in the major study.

Table 2. — Summary of analyses of variance of tracheid length, specific gravity, 1964 shoot length, and 1964 shoot diameter inside bark

Item	Source of variation		
	Replication	Seed source	Error
Degrees of freedom	4	33	132
Mean squares for:			
Tracheid length	.0552	.0789 **	.0065
Specific gravity	.00020	.00132 **	.00014
1964 shoot length	248.55	661.50 **	36.45
Diameter inside bark (1964 shoot)	54.42	105.74 **	5.91

** Significantly different at the 1-percent level

Table 3. — Correlation coefficients (r) between mean tracheid length, specific gravity, 1964 shoot length, and 1964 shoot diameter inside bark for 34 seed sources[1]

Characteristic	Tracheid length	1964 shoot length	Diameter i.b. (1964 shoot)	Specific gravity
Tracheid length	1.00	.91	.94	-.89
1964 shoot length		1.00	.96	-.85
Diameter inside bark (1964 shoot)			1.00	-.91
Specific gravity				1.00

1/ All values significant at the 1-percent level with 32 degrees of freedom.

Table 4. — Summary of covariance analyses; all F-values are significant at the 1-percent level

Dependent variable	Independent variable	Seed source F-value
Tracheid length	1964 shoot length	6.33
Tracheid length	Diameter inside bark	5.50
Specific gravity	Diameter inside bark	6.14

Setting the calculated mean squares from our analyses of variance equal to the expected mean square components (of a random effects model) and solving the components, we find that the between-stand genetic component in tracheid length variation is 2.3 times the error component. Since the error component contains the within-stand genetic variation plus measurement errors and within-plot environmental variation, clearly the between-stand genetic variance (for the seed sources represented here) is at least 2.3 times the within-stand genetic variance in tracheid length. Following the same procedure with specific gravity, we find that the between-stand genetic variance is at least 1.7 times the within-stand genetic variance in specific gravity.

Discussion

On the basis of the present study, selection of seed sources for higher specific gravity is apparently not feasible with trees of this age.

There are several reasons for this. First, the overall variation in specific gravity in juvenile wood is too low to allow any meaningful selection. If we eliminate from consideration the slow-growing sources from Nova Scotia and northern Canada and consider only those sources of potential use in a Lake States tree improvement program, we find only one seed source (from Fort Coulonge, P.Q.) that is significantly different from the remaining 22 sources. And this source is significantly lower in specific gravity than the rest. Moreover, the $LSD_{.05}$ is only 4 percent of the overall mean in specific gravity. It seems doubtful that an increased sampling intensity will increase the sensitivity of the test to the point where significantly higher specific gravity sources can be detected among the faster-growing seed sources.

Secondly, although there is a strong negative correlation between specific gravity and growth rate in this juvenile wood, Spurr and Hsuing (1954), after a comprehensive review of the literature, concluded that growth rate had only a minor effect on specific gravity in mature trees. Apparently, as the trees mature, factors other than growth rate assume an increasing importance in determining specific gravity. One such factor is summerwood percent which, in the southern pines (Larson 1957, Schafer 1949, and others), varies independently of growth rate. Attempts to determine the percent of summerwood in the present study were abandoned because of the small amount of summerwood present and because of the presence of false rings in many of the samples. Presumably the specific gravity of wood formed at an age when genetic variation in summerwood percent is evident would be more useful in predicting mature-tree specific gravity than is possible with the specific gravity of 3-year-old material.

The possibility of juvenile selection seems a little brighter for increased tracheid length than for specific gravity. If we consider only the fastest growing sources, we find several that have tracheid lengths significantly different from the others. The literature also suggests that as the trees mature: 1) the average seed source tracheid length will increase; 2) the differences between seed sources will increase; and 3) the source with the highest initial tracheid length may also yield higher tracheid lengths in older trees (Bisset *et al.* 1951, Dadswell and Wardrop 1960, Dinwoodie 1963). However, Dinwoodie's (1963) data on four Sitka spruce (*Picea sitchensis* (Bong.) Carr.) provenances showed that the ranking of the seed sources can shift with age, particularly among sources which did not differ greatly initially.

Thus, while proper seed source selection can result in increased tracheid length, selections based on very young material will probably result in a reduced genetic gain. The magnitude of this loss can only be determined by long-range studies.

Conclusions

1. Jack pine seed sources differ in tracheid length and specific gravity of 3-year-old wood.

2. In material of this age, strong positive correlations exist between mean seed source tracheid length, diameter inside bark, and annual height growth. Strong negative correlations exist between mean seed source specific gravity and tracheid length, diameter inside bark, and annual height growth.

3. With the widely diverse seed sources represented in this study, the between-stand component of genetic variation was much greater than the within-stand variation.

4. Seed sources from northern Canada and eastern Nova Scotia had the slowest growth rate, shortest tracheids, and highest specific gravity. Sources from Minnesota, Wisconsin, and Michigan had the highest growth rate, longest tracheids, and lowest specific gravity.

5. Tracheid length as estimated from 3-year-old wood may give a fair indication of mature-tree tracheid length when a wide range of genetic diversity is under investigation. Specific gravity of 3-year-old material is unlikely to be useful in predicting the density of mature trees.

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VARIATION IN BARK CHARACTERS AND WOOD SPECIFIC GRAVITY OF SUGAR MAPLE[1]

Robert L. Sajdak[2]

The external appearance of the bark of sugar maple (*Acer saccharum* Marsh.) has been described as "deeply furrowed," "fissured with long irregular thick plates or ridges," "somewhat scaly," "sometimes curling," and "highly variable." Adjacent trees in natural stands often have strikingly different external bark characteristics.

Gross variability in bark appearance is unusual within a species. In general, bark appearance is relatively constant, and any variability encountered is often a reflection of vigor. Indeed, some researchers consider external bark characteristics to be helpful in log and tree grading and quite reliable as an indicator of tree vigor (Burkle and Guttenberg 1952, Arbogast 1957). Kennedy and Wilson (1954) in studies of smooth and cork-bark alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) show that a strong relationship exists between age and bark type for four diameter classes. The cork-bark type is consistently older.

The objective of this study was to investigate what relationships may exist between bark type, age, diameter, growth rate, and wood specific gravity in sugar maple.

Materials and Methods

Sixty-one trees were selected from an area of about 30 acres on Copper Range Company lands in Houghton County, Michigan. The stand is predominantly sugar maple and had been selectively logged twice. The site is a fairly uniform loamy sand, deep and well drained with no extreme topography. The stand was selected because it has a good diameter distribution, from 12 to 24 inches d.b.h., and considerable bark variation was noted throughout these classes. Measurements and stereophotographs were taken of the bark. Because of the difficulty in quantifying external bark characteristics, qualitative descriptions were also recorded.

One 8 mm increment core, extending to the pith, was removed from each tree at breast height. The position of extraction was random except for leaning trees; in these, the cores were extracted at right angles to the direction of lean. The cores were placed in water and stored frozen until processed in the laboratory.

The characteristics determined from these cores were: (1) Total age at breast height, (2) growth rate, by averaging the rings per inch for the last 3 inches of radial growth, and (3) wood specific gravity based on green volume and oven-dry weight for each inch of core from the pith outward.

Bark Classes

From many field observations and from a study of the bark photographs, four fairly distinct bark classes were defined:

Bark type 1. — This type is termed "platy" (fig. 1). It could be considered as typical and was most common in the sample. The bark plates are relatively flat and are much broader than the furrows. Occasionally the plates curl and the bark is firm. The furrows are relatively narrow and *V*- or *U*-shaped in cross-section. The furrows have a prominent vertical pattern and are usually ½-inch or less in depth.

Bark type 2. — This type is termed "corrugated" (fig. 2) and usually has a fairly uniform pattern. In large trees the bark resembles that of old-growth red oak (*Quercus rubra* L.). In smaller trees, it resembles white or green ash (*Fraxinus americana* L., *F. pennsylvanica* Marsh.). The bark has ridges and furrows of equal width and is quite firm. The ridge crowns are mostly rounded and the furrow bottoms are rounded or V-shaped in cross-section. The furrows have a prominent vertical pattern and are usually over ½-inch in depth.

Bark type 3. — This type is termed "shell bark" (fig. 3) and resembles somewhat the bark of jack pine (*Pinus banksiana* Lamb.) or black cherry (*Prunus serotina* Ehrh.). It is similar to the platy type, but the plates are of various sizes and often

[1] *This study was partially supported with funds from the McIntire-Stennis Cooperative Forestry Research Program of the U.S.D.A.*

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FIGURE 1. — Type 1 bark ("platy"). Tree is 22.6 inches d.b.h. at 142 years. Rapid growth rate.

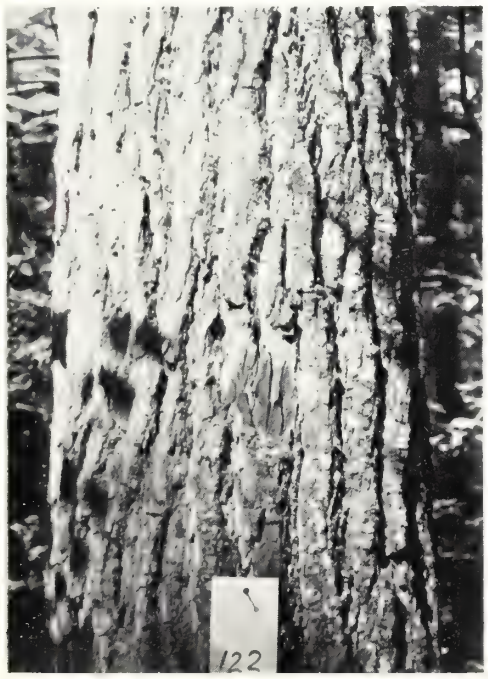

FIGURE 2. — Type 2 bark ("corrugated"). Tree is 20.8 inches d.b.h. at 227 years. Medium growth rate.

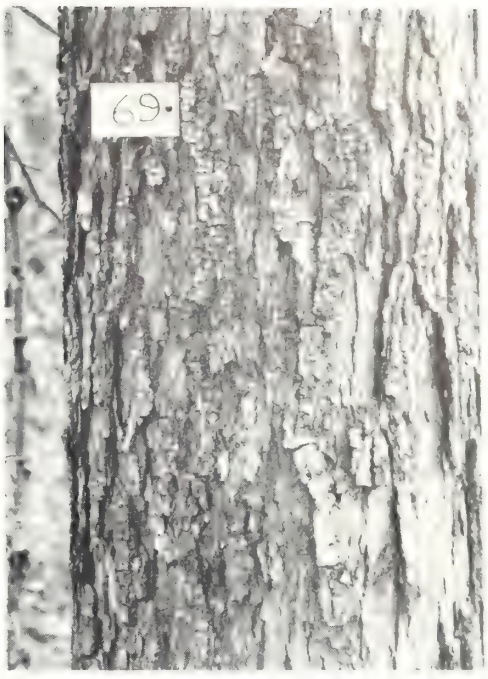

FIGURE 3. — Type 3 bark, ("shell"). Tree is 14.4 inches d.b.h. at 129 years. Medium growth rate.

FIGURE 4. — Type 4 bark, ("ropy"). Tree is 11.5 inches d.b.h. at 83 years. Medium growth rate.

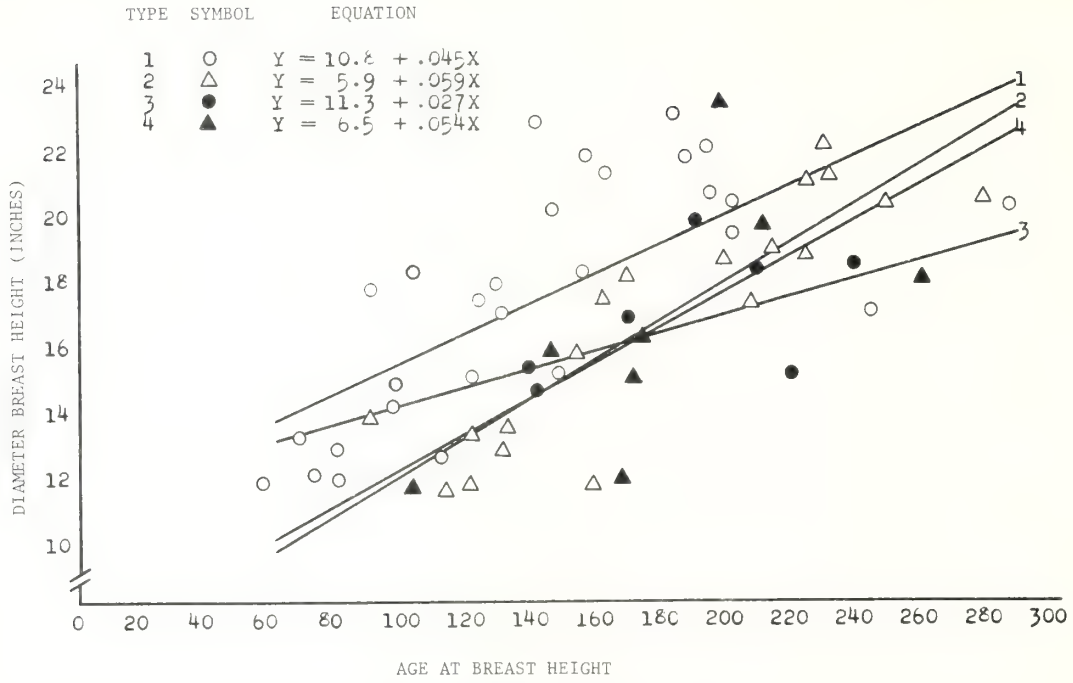

FIGURE 5. — Relationship between diameter breast height and age at breast height for four bark classes.

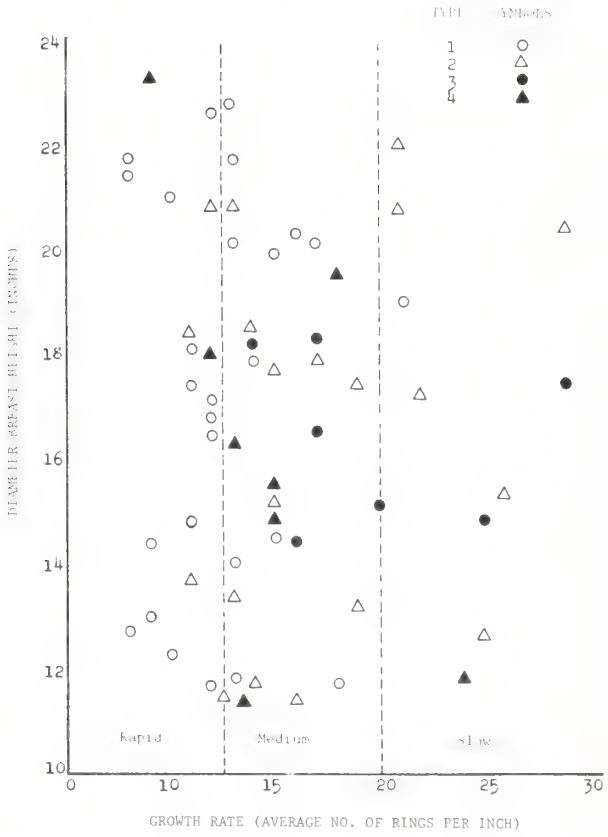

FIGURE 6. — Distribution of sample trees by d.b.h. and growth rate for four bark types. Growth rate is the average number of rings per inch based on the last 3 inches of radial growth.

overlapping. Crossbreaks are common. The furrows are of various depths and have very little vertical pattern.

Bark type 4. — This type is termed "ropy" (fig. 4). It resembles the common hackberry (*Celtis occidentalis* L.). It is similar to the corrugated type except the furrows are very broad and flat in relation to the size of the ridges.

Relationship of Bark Type to Diameter and Age

The relationship of bark type to diameter and age at breast height (fig. 5) indicates that trees with bark type 1 may be the most vigorous. The distribution also indicates that a diameter-limit cut has been practiced in this stand since no trees over 24 inches d.b.h. were found. This practice would tend to remove the more vigorous trees and thus the slope of the regression line for bark type 1 may be lower than in stands with no limit on diameter.

Since nearly one-half of the sample trees are of bark type 1 (N=28), the regression of this type was tested against the combined regression of bark types 2, 3, and 4 (N=34) by covariance analysis. The first step in this analysis is a test of parallelism of the two regression lines. This test was not significant at the 0.05 level. Having found no significant difference in slopes, the next test was to determine whether the regressions differ in level. This test was significant at the 0.01 level.

In figure 6, no relationship is indicated between

bark type and diameter, but a strong relationship is indicated between bark type 1 and the rapid growth rate class. Seventy-five percent of the trees in this class have bark type 1. These data also indicate that some large-diameter trees have a capacity for rapid growth rate.

Specific Gravity

The average specific gravity of the sample trees is .586 compared to .56 as reported in the Wood Handbook (1955) and .585 as reported by Paul (1963) based on samples from 70 trees from 12 stands in 8 states.

Bark type 1 trees tend to have slightly less dense wood (fig. 7); their mean specific gravity is 0.579 while the mean of trees with types 2, 3, and 4 bark is 0.591. Statistical analysis based on the *t* test for group comparisons indicates this difference is significant at the 0.05 level.

Specific gravity in relation to position at breast height (fig. 8) for all trees indicates a high specific gravity near the pith followed by a decrease, then an increase. This conflicts with reports by Lisboa (1961) and Webb (1964) who showed that in some diffuse-porous hardwoods (black willow (*Salix nigra* Marsh), sweetgum (*Liquidambar styracflua* L.) specific gravity is lowest near the pith, and increases and then decreases with age. In this study, however, variation in specific gravity was recorded by position in inches from the pith and not as a function of age. Variation in number of rings per inch was very large, ranging from 10 to 50 rings per inch for the position nearest the pith and from 4 to 65 rings overall.

Correlation coefficients were computed to determine if growth rate was related to specific gravity by position. At no position was a significant correlation obtained. The amount of variation explained by growth rate (rings/inch) at each position was very small, as shown by the coefficient of determination values (r^2) in table 1. This disagrees with Paul (1963) who found growth rate was related to specific gravity after the first or second inch from the pith in sugar maple.

Some of the differences found between this study and other reports may possibly be due to the occurence of mineral stain. Mineral stain in maple is difficult to differentiate from normal

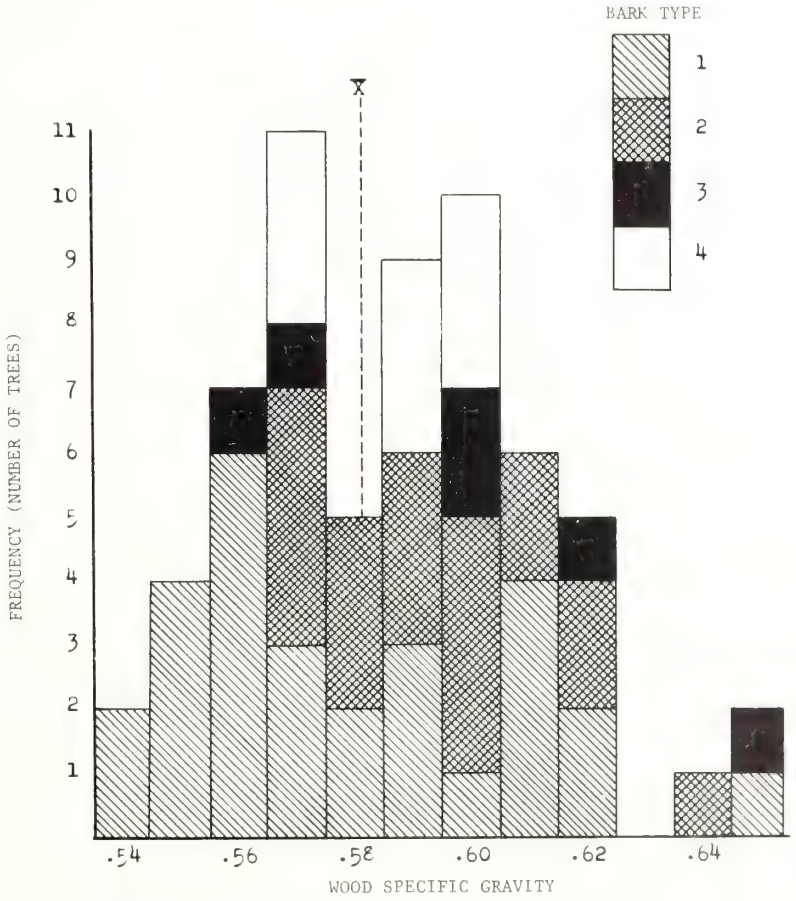

FIGURE 7. — Relationship of bark type and wood specific gravity.

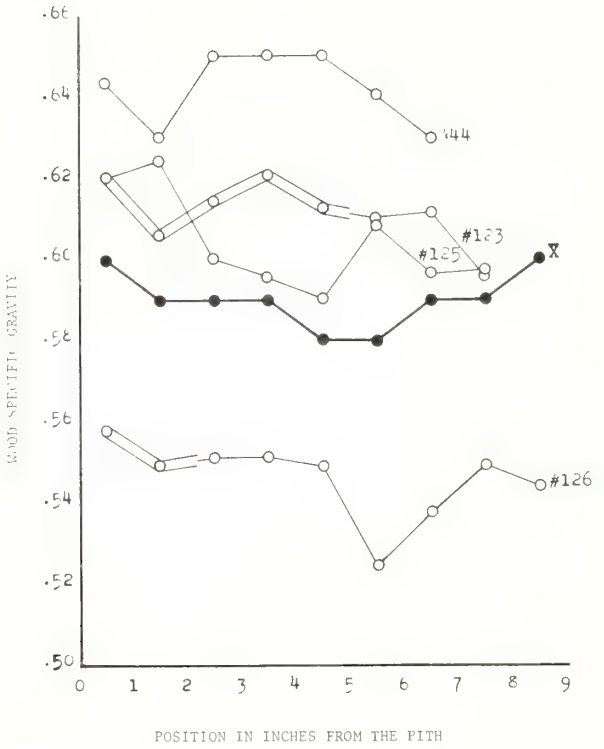

FIGURE 8. — Variation in specific gravity at breast height in relation to position for the average of all trees and for four selected individual trees. The double lines indicate the amount of heartwood.

heartwood. It occurs in the heartwood and in scattered pockets in the sapwood and thus may increase the specific gravity by a significant amount (Good *et al.* 1956, Seidel 1948). Future studies of specific gravity in sugar maple should take mineral stain into consideration, perhaps by ashing the wood and subtracting the weight of ash from the oven-dry weight of the wood.

Summary and Conclusions

The trees in this study were selected because they had a definite bark appearance. It must be stressed, however, that the variation in sugar maple bark is usually continuous; gradations among the four types given here were found on the study area.

The single most consistent indicator of tree vigor as found in bark appearance is the thickness of the outer bark or the depth of furrows. The furrows must be in a prominent vertical pattern and the plates firm.

Bark types are not common to a particular diameter group. Slightly more than one-half the bark type 1 trees are growing at a rate of less than 13 rings per inch as averaged over the last 3 inches of radial growth.

Specific gravity based on the average of 61 trees in a 30-acre stand closely agrees with the average as reported from 12 stands in 8 states. Growth rate and specific gravity are not correlated to a significant degree.

Table 1. — Coefficients of correlation between specific gravity and rings per inch

Position (in. from pith)	n	r	r^2
1	47	.030	.0009
2	58	.108	.0117
3	58	.145	.0210
4	59	.044	.0019
5	55	.023	.0005
6	45	.078	.0061
7	40	.207	.0428
8	23	.000	.0000

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SPECIFIC GRAVITY RELATIONSHIPS IN PLANTATION-GROWN RED PINE

Gregory Baker and James E. Shottafer[1]

Norway or red pine (*Pinus resinosa* Ait.) has been popular in Maine for forest planting because it will rapidly convert grass and weed cover to a forest floor and because it is relatively free from attack by insects and diseases. Since the first commercial thinnings consist of small-sized trees, the most logical market outlet is for pulpwood. Yield of pulp fiber by weight is directly correlated with the specific gravity of the wood. Consequently, several questions arise: What is the average specific gravity of plantation red pine of a given age? Can the tree specific gravity for young, plantation-grown red pine be predicted satisfactorily by the technique used in predicting tree specific gravity of mature, natural-grown red pine? How do some of the variables encountered affect specific gravity of red pine plantations of the same age?

A method of estimating tree specific gravity from increment cores taken at breast height has been reported in numerous publications and for several species of trees. In most cases the method has been applied to mature, natural-grown trees. A McIntyre-Stennis financed pilot study was initiated to test this method on young, plantation-grown red pine, and to study such other variables as could be measured without adding significantly to the cost of the study.

The Plantation

The stand from which the sample trees were selected was planted with 2-1 stock in 1941 and 1942. At the time of cutting, in 1964, the trees were 25 and 26 years old from seed. Five paired blocks 75x100 feet were planted with tree spacings of 2, 4, 6, 8 and 10 feet. In Area No. 1 thinning was to be done as required for good growth. Area No. 2 was left as a check. At the time of sampling, the 2-foot spacing in Area No. 1 had been thinned to 4x4 feet and the 4-foot spacing had been thinned to 8x8 feet.

Sample Tree Selection

Ten trees were selected from each of the 10 blocks. The criteria for selection were that they should have dominant or codominant crowns, single leaders, and no pronounced lean from the vertical — in brief, what might be considered good crop trees to bring to maturity. These trees were randomly selected from the stand, avoiding only the trees on the outer rows.

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Sample Collection

Tree diameter, total height, merchantable height (to a 4-inch top), and length of live crown were measured. Destructive sampling followed standard procedures:

1. Two increment cores at breast height. Random position of first; second at 90° to right.
2. Tree felled, cut into bolts 4.2 feet long.
3. Disks 2 inches thick cut from the top of each bolt and average diameter measured.

Laboratory Determinations

The increment cores were processed to determine specific gravity on a green volume-ovendry basis, and the values averaged for each tree.

The specific gravity of the disks was determined by the method developed by Heinrichs (1954).

Computations

Average weighted tree specific gravity was determined by averaging the specific gravity of the disks at each end of a bolt, multiplying the average by the volume of the bolt in cubic feet, totaling the values, and dividing by the total merchantable volume of the tree.

Average specific gravity of the disks at 4-foot height, 8-foot height, etc., was determined for each 10-tree group and for the entire 100 trees.

Analysis of Data

All data were transferred to IBM cards. A regression analysis was made to establish the equations for predicting average tree specific gravity from the specific gravity of two increment cores at breast height. Wahlgren *et al.* (1966) developed equations for predicting tree specific gravity from increment cores in natural-grown red pine stands. Setting Y equal to average tree specific gravity, and X equal to specific gravity of 2 cores, the equations are:

Plantation-grown: $Y = 0.20564 + 0.35193\ X$
$R^2 = 0.4089$
$F = 27.78$ which is significant to the 1-percent level

Natural-Grown: $Y = 0.20517 + 0.43648\ X$
$R^2 = 0.3780$

Since Wahlgren *et al.* sampled several age classes in the natural-grown red pine, they were able to introduce diameter over age into another equation with significant improvement in the predicting equation; the R^2 was 0.6831. The plantation red pine being of one age, this variable of age could not be used.

Figure 1 shows the two equations on the same graph. While the lines are nearly parallel, indicating a similar relationship between X and Y variables, it is obvious that two distinct populations are involved. The plantation-grown red pine had a mean specific gravity of 0.322 while the natural-grown red pine had an average tree specific gravity of 0.391. The regression line for Wisconsin plantation-grown red pine, reported by Maeglin (1966), assumes a quite different slope, i.e., tree specific gravity increases more rapidly with increase in core specific gravity than in the Maine studies.

Further work is planned to sample successively older plantations in Maine (to about 50 years) to study the effect of age on the regression equation.

Within-Tree Specific Gravity Variation

Within-tree variation in specific gravity has been studied in many species of trees, principally mature, natural-grown trees. In Wahlgren *et al.* (1966) the generalized pattern of specific gravity of the cross-section was a decrease with increased height above the ground for red pine. Maeglin (1966) in his study of red pine plantations in Wisconsin concluded that, except for age differences, the data from plantation-grown red pine of Wisconsin appeared to agree with that of the natural-grown red pine of Maine (fig. 2).

A different pattern of specific gravity distribution vertically in the tree was found in the 25-year-old plantation in Maine. Several groupings of the data were made:

1. Data from all trees (100) were averaged and plotted. This graph (fig. 3) shows a distinct drop in specific gravity from the 4-foot to the 8-foot

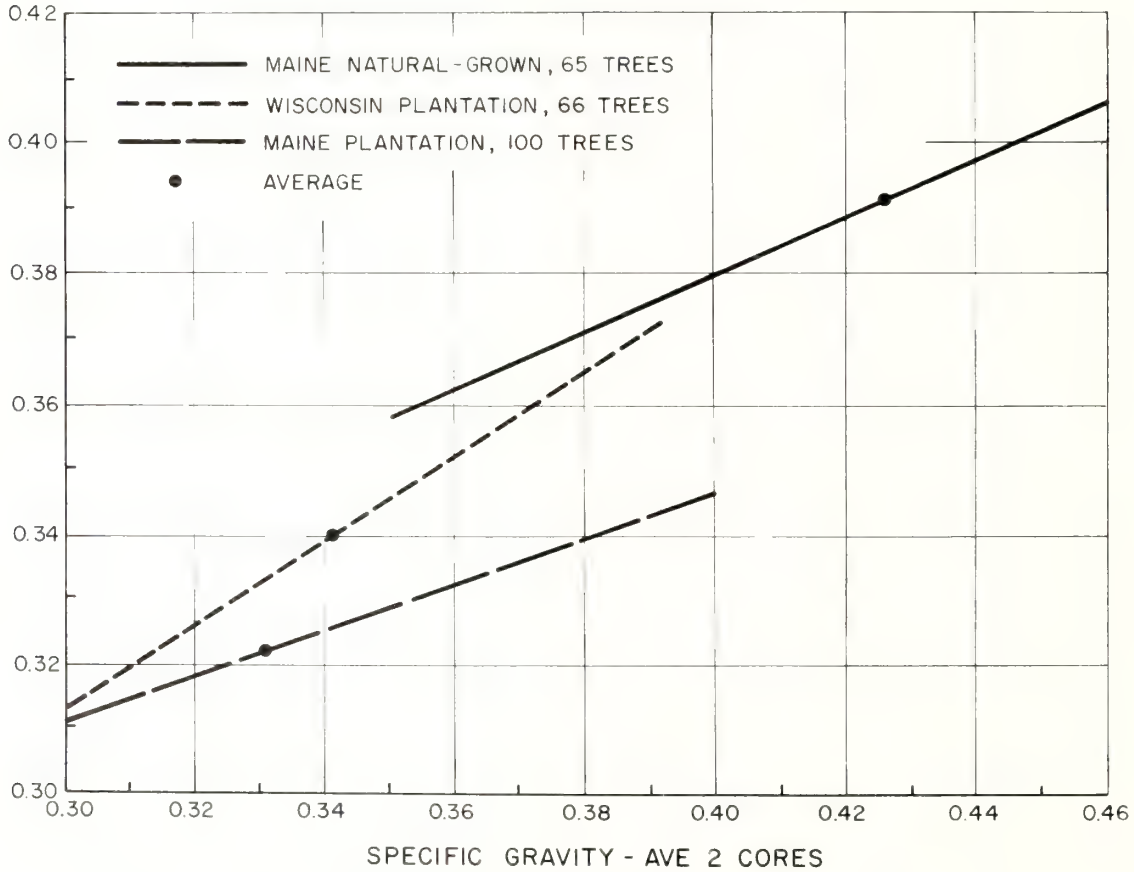

FIGURE 1. — Relationship of core specific gravity to tree specific gravity for red pine. Maine data for natural grown pine from Wahlgren *et al.* (1966); Wisconsin data from Maeglin (1966).

height and then a gradual but consistent increase in specific gravity upward in the tree.

2. Data were grouped by merchantable height classes so that at each level above the ground there were the same number of samples.

a. The data from the shortest merchantable height class (16.8 feet) when plotted show a consistent increase in specific gravity with increase in height.

b. The 21.0-foot and 25.2-foot classes show the same pattern as the all-tree graph.

c. The 29.4-foot class, which was represented by only 3 trees, shows a drop in specific gravity to the 8-foot and 12-foot level, followed by an increase in the 21-foot height and then a leveling off of specific gravity values to the 29.4-foot level.

3. Analysis by tree-spacing blocks of 10 trees each. Here, examination of the data for the two extremes of spacing, 2x2 feet and 10x10 feet, of the check blocks (no. 2 planting) gives the following comparisons:

Average —	*2-foot spacing*	*10-foot spacing*
Diameter (b.h.) inches	4.80	6.90
Total height, feet	34.00	30.00
Merchantable length, feet	20.20	18.50
Volume to 4-inch top, cu. ft.	1.83	2.97
Length of live crown, feet	15.50	22.20

In the 2-foot spacing there is a continuous drop in specific gravity from breast height to a 4-inch merchantable top. This pattern is similar to that found in natural-grown red pine in Maine (Wahl-

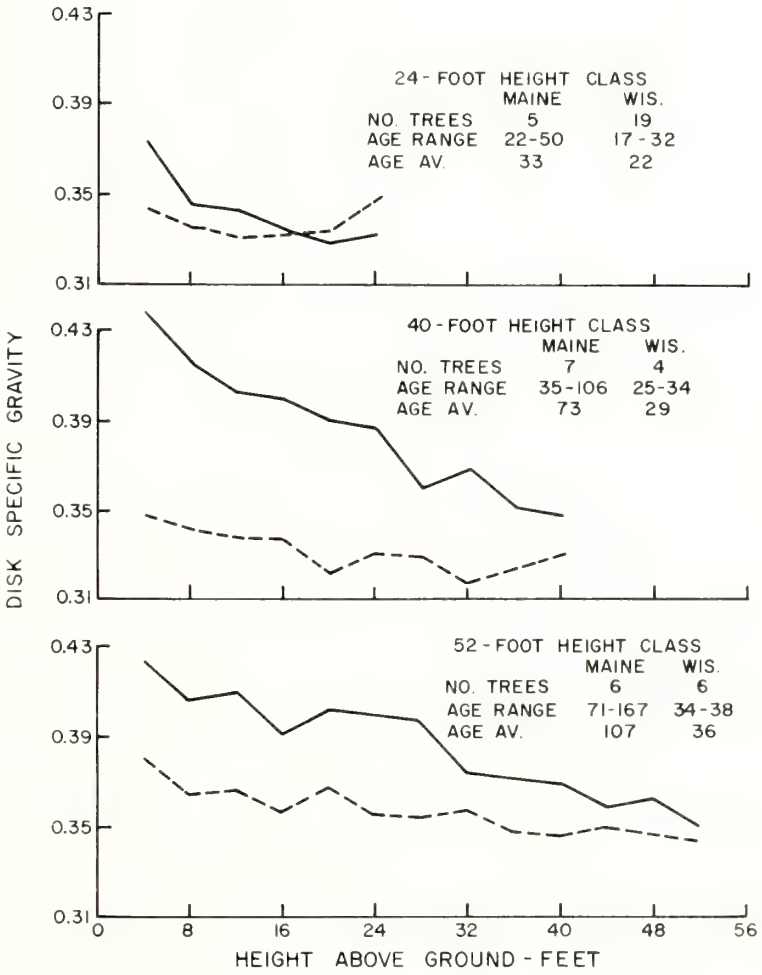

FIGURE 2. — Relationship of three height and age classes to disk specific gravity for red pine. Maine data on natural-grown red pine (solid line) from Wahlgren *et al.* (1966); Wisconsin data on plantation-grown red pine (broken line) from Maeglin (1966).

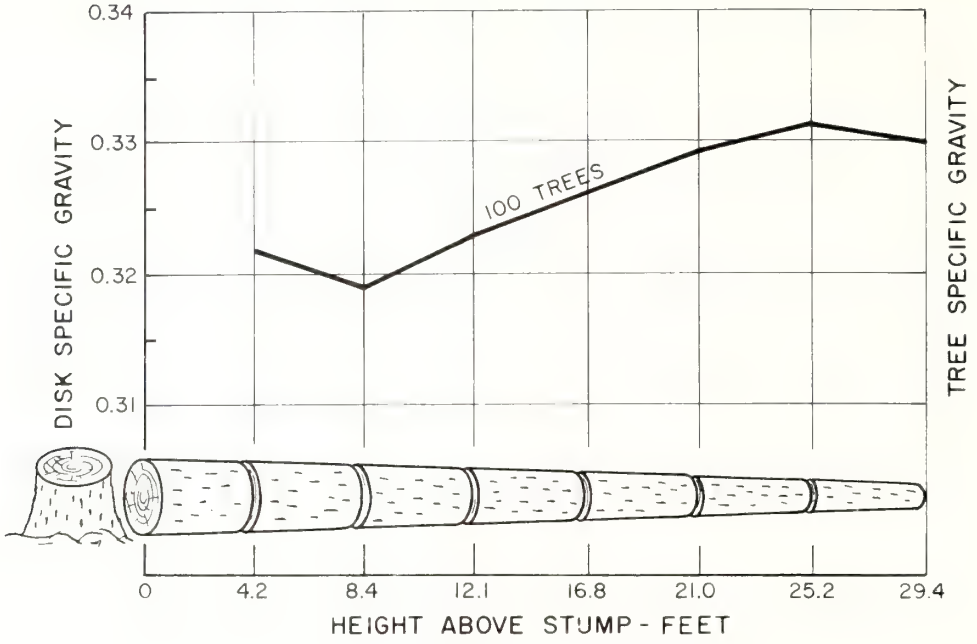

FIGURE 3. — Average specific gravity at various heights above stump for red pine.

gren *et al.* 1966), although the average values are lower (average tree specific gravity 0.325 vs. 0.391) (fig. 4). In the 10-foot spacing, however, the above pattern was reversed, i.e., specific gravity *increased* from breast height to merchantable top (average tree specific gravity 0.318).

Since the tree age is the same in the two areas, the cause for these differences would appear to be in the growth and form of the trees. The trees in the 2-foot spacing have a smaller average diameter, greater total height with consequently less taper to the trunk, and a live crown average length which is shorter by nearly 7 feet.

This leads us to the tentative conclusion: When comparing plantation-grown trees of the same age, those which have been grown under severe crowding (close spacing) will have the least taper and the smallest diameter. They will average higher

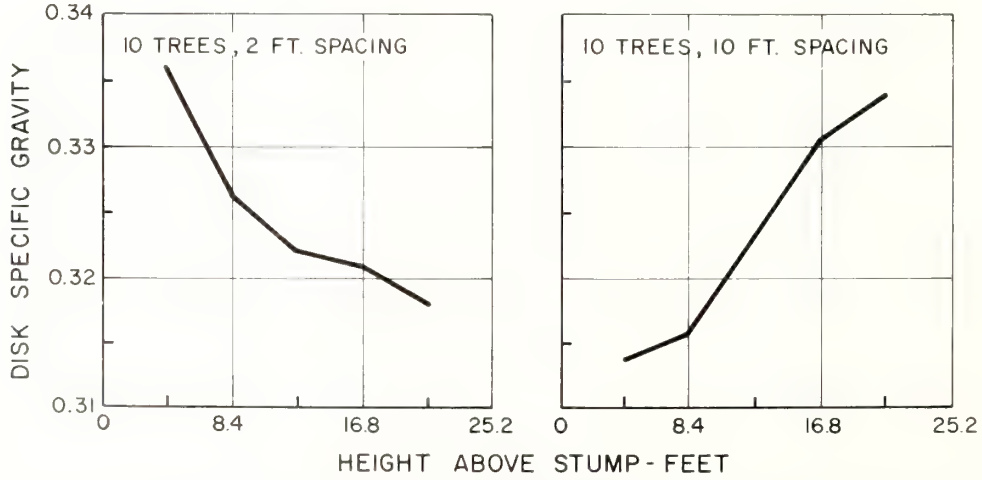

FIGURE 4. — Average disk specific gravity at various heights above stump for red pine.

in specific gravity, and the specific gravity will decrease with height above the ground. Conversely, trees grown at a wide spacing, with larger diameters, more rapid taper, and longer crowns, will average lower in specific gravity, and the specific gravity will increase with height above the ground.

Statistical analysis of the tree specific gravity data (Table 1) has indicated that in no case did a test block, or spacing group, differ significantly from its corresponding control block, unless treatment (thinning) had been involved. A linear trend toward significance was evident, with progressively wider spacings in the central area, until the 95-percent level was reached between the 2x2 and 10x10 blocks. The interaction between areas and blocks was far below any reasonable significance level, however, indicating a uniform response in both test and control areas to spacing changes.

The specific gravity of the trees in the 2x2 spacing that had been thinned to 4x4 was significantly higher than the 4x4 spacing that was thinned to 8x8. As noted above, this difference was not evident in the control blocks, nor was any difference between these blocks and the control blocks with original 4x4 and 8x8 spacing significant. A final comparison of all spacings 8x8 at the time of cutting (8x8 test, 8x8 test-thinned, and 8x8 control) did not indicate any significant differences in tree specific gravity. In all instances, the 95-percent level of significance was applied to the evaluation of the data.

Table 1. — Average tree specific gravity values for various spacings of plantation-grown red pine

Original spacing (ft.)	Area 1 (test)	Area 2 (control)
2x2	1/ 0.325	0.328
4x4	2/ .321	.328
6x6	.325	.324
8x8	.319	.321
10x10	.318	.318
Area average	.322	.323

1/ Thinned to 4x4 spacing.
2/ Thinned to 8x8 spacing.

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PHOTOSYNTHESIS AND GROWTH OF SELECTED SCOTCH PINE SEED SOURCES[1]

John C. Gordon and Gordon E. Gatherum[2]

A number of problems related to the culture of Scotch pine (*Pinus sylvestris* L.) arose following the increased planting of this species in Iowa. Therefore, a program of controlled-environment experiments to determine the effects of genetic and environmental factors on physiological processes important to the culture of Scotch pine was begun by the Iowa Agricultural Experiment Station. We will report here the results of some of these experiments, done by ourselves and students of the junior author. Some of these results have been published elsewhere, and some have not.

As pointed out by Gatherum (1964), the two principal objectives of the controlled-environment studies are to (1) permit further identification and evaluation of within-species variation of physiological processes in Scotch pine seedlings, and (2) provide a clearer understanding of causes of variation in tree vigor and quality. Because photosynthesis and respiration may be viewed as the basic yield-determining physiological processes in plants, they were selected as dependent factors, measured by the variables CO_2 uptake and CO_2 evolution, respectively. Growth, as measured by the variables fresh and dry weight and stem and needle elongation, was also considered as a dependent factor in the studies to be reported. In making comparisons among treatments and in relating photosynthesis to growth, we defined the two additional dependent factors, photosynthetic capacity and photosynthetic efficiency. Photosynthetic capacity, as we use the term, is measured by the rate of CO_2 uptake of the entire aerial portion of the seedling. Photosynthetic efficiency, on the other hand, is measured by the rate of CO_2 uptake per unit of photosynthesizing foliage. Photosynthetic efficiency is, then, photosynthetic capacity divided by foliar quantity.

The independent factors we studied in relation to photosynthesis and growth were seed source, as indicated by the geographic origin of the seed from which the seedlings were grown, and several factors of the environment important in influencing the physiology of trees: photoperiod, temperature, nitrogen, and light intensity. The specific questions about Scotch pine that these studies were intended to answer were:

1. Does seed source affect photosynthesis and respiration?

2. Do seed source and environmental factors interact in their effect on photosynthesis and respiration?

3. How do the effects of these factors on photosynthesis and respiration relate to their effects on growth?

Materials and Methods

Although the Scotch pine seed sources used (table 1) represent a fairly wide range of latitude, they do not, either randomly or systematically, sample the entire native range of the species. Environmental treatments, when applied before measurement of CO_2 exchange, were carried out in the greenhouse. Environment was controlled during measurement of CO_2 exchange in a chamber described by Broerman *et al.* (1967). Rates of photosynthesis and respiration were measured by monitoring CO_2 uptake and evolution in a closed system with an infra-red CO_2 analyzer.

Results and Discussion

To bring together the results of the several studies, we discuss seed source in conjunction with each environmental factor studied. This is done for convenience, and is not meant to imply that

Table 1. — Scotch pine seed sources used, ISU studies

ISU no. and seed source	Latitude	Longitude	Elevation
	°N	°E	(Meters)
211; Finland	66	26	150
210; Finland	62	24	100
208; Finland	60	23	15
217; USSR	57	25	100
216; Poland	54	20	140
214; Czecho-slovakia	50	16	780
81; Germany	50	9	--
215; Czecho-slovakia	49	21	690
82; Austria	48	16	450
218; Bulgaria	42	25	1,220
113; Turkey	40	33	1,500
115; Turkey	40	31	1,400

[1] *Journal Paper No. 5771 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1582.*

[2] *Respectively graduate student and Professor of Forestry, Iowa State University, Ames (now with N. Cent. Forest Exp. Sta.). Dr. Gordon is now on the staff of the Institute of Forest Genetics, North Central Forest Experiment Station, Rhinelander, Wis.*

seed source influences CO_2 exchange and growth separately and independently with each of the environmental factors.

Photoperiod

We have not investigated the effect of seed source and photoperiod on photosynthesis directly. However, the effects of seed source and photoperiod on growth and development were studied in first-year seedlings by Jensen and Gatherum (1965). They demonstrated that seed source and photoperiod interact in their effect on height growth and needle elongation. The data indicated that photoperiod could be an environmental factor important in natural selection, since it definitely affected patterns of growth and differentiation in first-year seedlings. The ability of some sources to produce a greater quantity of foliage than others in response to a given photoperiod suggested a relationship between seed source and photosynthetic capacity.

Temperature

Temperature interacted with both photoperiod and seed source in its effect on height growth and needle elongation (Jensen and Gatherum 1965). It did not, however, interact with seed source in its effect on photosynthesis and respiration in second-year seedlings from three sources (208, 216, 214). It is possible that the parent climates of the three sources used in the photosynthesis study are similar enough in growing-season temperatures to preclude differential adaptation of the photosynthetic and respiratory processes to temperature. Additional controlled-environment experiments including more seed sources and more refined physiological measurement are needed before final conclusions about the interacting effects of seed source and temperature on photosynthesis and respiration can be drawn.

Nitrogen

In a study including five seed sources ranging from Bulgaria to Finland (218, 216, 217, 208) and five sand culture nitrogen levels (25 to 500 ppm), nitrogen and seed source had an interacting effect on shoot fresh weight, but not on dry weight, photosynthesis, or respiration (Dykstra and Gatherum 1967). Optimum nitrogen (approximately 400 ppm) increased photosynthetic capacity in all sources, but resulted in a slightly lower photosynthetic efficiency. Probably, part of the reduction in efficiency can be accounted for by mutual shading of needles in the larger-crowned seedlings produced at optimum nitrogen level. However, it is possible that biochemical differences in the distribution of assimilate within the needles also contributed to the reduction.

Light Intensity

Light intensity and seed source interacted in their effect on photosynthetic capacity in an experiment including fourth-year seedlings from four sources (81, 82, 113, 115) (Gatherum *et al.* 1967). Photosynthetic capacity increased with light intensity in the Austrian source up to the highest test intensity, while the German and Turkish sources appeared to reach light saturation (maximum capacity) at lower intensities (fig. 1). No differences in photosynthetic efficiency were observed. This suggests that the differential response to light among the sources was due to differences in quantity and arrangement of foliage, rather than to inherent biochemical differences in the photosynthetic process itself.

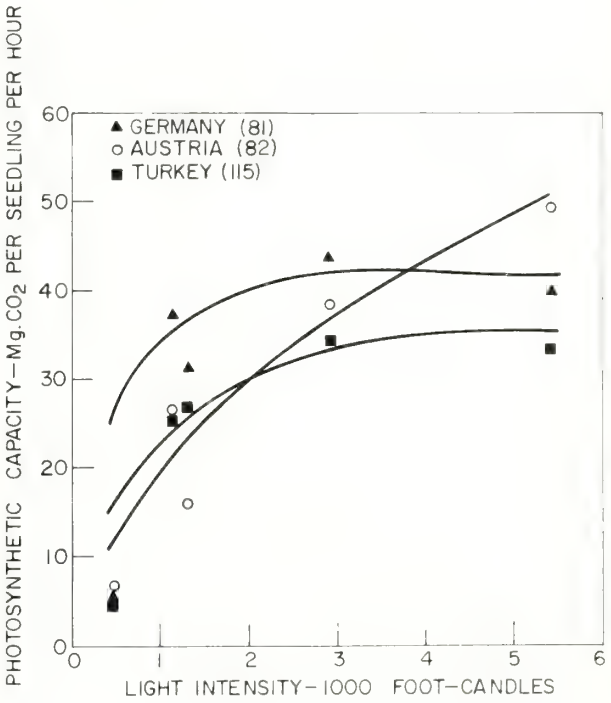

FIGURE 1. — Relationship between photosynthetic capacity and light intensity for fourth-year seedlings of three sources. ISU seed source number is shown in parentheses.

In a subsequent study of first-year seedlings that included eight seed sources (211, 210, 208, 217, 216, 214, 215, 218) and three light intensities (3,000, 6,000 and 9,000 foot-candles), photosynthetic capacity and efficiency both were influenced by the interaction of seed source and light intensity (fig. 2). The interaction appeared to be limited to the two most northerly sources. However, when second-year seedlings of three of the eight sources were tested at the same and at six lower light intensities, no differences in efficiency were

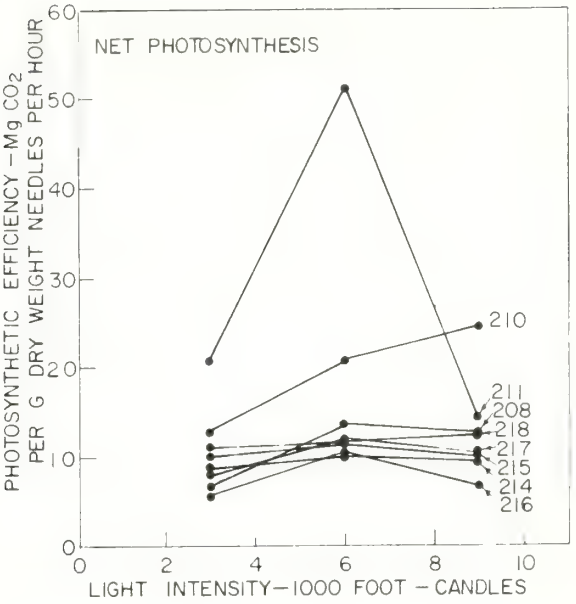

FIGURE 2. — Relationship beteen photosynthetic efficiency and light intensity for first-year seedlings of eight sources. The trend lines are identified at the right by ISU seed source number.

observed. But again, seed source and light intensity interacted in their effect on photosynthetic capacity.

Taken together, these results imply a basic difference in the photosynthetic properties of the crown between first-year and older Scotch pine seedlings. One probable cause of the difference is the presence of a high proportion of functional juvenile needles on first-year seedlings.

Photosynthesis and Growth

Differences among seed sources in photosynthetic efficiency, photosynthetic capacity, growth, and distribution of assimilate (dry weight) were observed in a study including first-year seedlings from eight sources. Photosynethic capacity and seedling height, fresh and dry weight were positively related. Photosynthetic efficiency, however, was inversely related to height, fresh and dry weight, and photosynthetic capacity (table 2). Seedlings that retained the lowest percentage of their total dry weight in their needles had the highest photosynthetic efficiency, and were from the northernmost sources (table 3). This relationship between high photosynthetic efficiency, low photosynthetic capacity and distribution of assimilate may be accounted for by (1) less mutual shading of needles on small-crowned seedlings or

Table 3. — Effect of seed source on percentage distribution of assimilate in first-year seedlings

ISU no. and seed source	Percentage of total dry weight in--		
	Needles	Stem	Roots
211; Finland	41	14	45
210; Finland	46	15	39
208; Finland	55	13	32
217; USSR	56	11	33
216; Poland	54	17	29
214; Czechoslovakia	60	13	27
215; Czechoslovakia	58	12	30
218; Bulgaria	58	14	28

Table 2. — Effect of seed source on fresh and dry weight and photosynthetic capacity and efficiency of first-year seedlings

ISU no. and seed source	Total fresh weight	Total dry weight	Photosynthetic capacity	Photosynthetic efficiency
	g.	g.	mg.CO_2/hr./seedling	mg.CO_2/hr./g. dry wt. needles
211; Finland	3.1	1.2	5.0	52.5
210; Finland	10.5	4.6	8.3	21.0
208; Finland	17.0	7.1	13.2	13.1
217; USSR	14.2	5.9	9.0	12.2
216; Poland	16.2	6.6	10.5	10.7
214; Czechoslovakia	24.5	9.9	14.0	9.6
215; Czechoslovakia	23.0	9.7	14.9	10.8
218; Bulgaria	18.9	7.7	11.2	12.0

(2) less deposition of storage and structural, non-photosynthetic compounds in the needles, or both. Higher photosynthetic efficiency also may be related to the greater contribution of juvenile needles to total needle weight of the seedlings of the northernmost sources. In any case, the higher photosynethic efficiency of these sources obviously does not represent any sort of "photosynthetic superiority" in the sense of more efficient total dry weight production.

Respiration and Growth

Rates of respiration per seedling and, under some treatments, per gram of needles, varied among seed sources in second-year and older seedlings. No differences in respiration per gram of needles were observed in first-year seedlings, but, as expected, larger seedlings respired more than small ones. The relationship of respiration to growth, in a sense, is more complex than that of photosynthesis. Presumably, any increase in rate of photosynthesis represents a potential increase in dry weight production. It is not true, however, that an increase in respiration necessarily decreases dry weight production. While substrate is oxidized to H_2O and CO_2 during aerobic respiration, and an immediate reduction in dry weight occurs, the chemical bond energy thus generated is necessary for growth processes. Thus, a high respiration rate accompanies the production of new needle tissue. The production of new needle tissue, in turn, can result in greater dry weight production through increased photosynthetic capacity. What should be avoided are seedlings and environmental conditions that result in "excess" respiration. This, however, is extremely difficult to define, let alone identify.

Conclusions

1. Seed source does affect rates of photosynthesis and respiration. However, our work has revealed no differences among sources in photosynthetic efficiency of seedlings older than one year.

2. Seed source and environmental factors can have an interacting effect on photosynthesis and respiration. More controlled-environment experimentation with more seed sources and wider ranges of environmental conditions is needed if the mechanisms of the interactions are to be understood.

3. Photosynthesis, respiration, and growth, as measured in these studies, are not related in a simple manner. A seed source exhibiting rapid growth does not necessarily have a high photosynthetic efficiency, as the term has commonly been used.

4. More physiological and biochemical research is needed if differences among sources in photosynthetic capacity, efficiency, and distribution of assimilate are to be satisfactorily explained. Ideally, such research should precede the use of photosynthesis and respiration characteristics in seed source selection.

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WOOD PROPERTY VARIATION IN POPULUS

Dean W. Einspahr, Miles K. Benson, and John R. Peckham[1]

The use of bigtooth aspen (*Populus grandidentata* Michx.), quaking aspen (*P. tremuloides* Michx.), and cottonwood (*P. deltoides* Bartr.) by the pulp and paper industry has increased greatly during the past decade. This expanded use has stimulated research on the genetic improvement of *Populus*. For the past 12 years an industry-sponsored aspen program has been underway at The Institute of Paper Chemistry (Einspahr and Benson 1964). One of its major goals has been the improvement of wood properties important to pulp and paper quality. During these 12 years a number of selected trees were evaluated and a number of studies have been completed in which wood, fiber, and pulp properties were obtained for individual trees.

This report summarizes wood property measurement data for several species of *Populus* and for both natural and artificially produced aspen hybrids. Although the nature of the data prevents any rigorous statistical treatment, comparable sampling and measurement techniques employed in the several studies permit useful comparisons between native species of *Populus* and the younger aged plantation-grown hybrids.

Materials and Methods

The older trees used in this comparison were growing in natural stands and either were selected for use as parent trees because of form and rate of growth or were randomly located trees that were being evaluated in studies of heritability or natural variation. Ten-millimeter, breast-high increment cores were used as a source of wood from the older trees. At least two cores were used in making the specific gravity and fiber length measurements, and additional cores were taken when micropulping information was determined.

The young trees used had been field planted as 1-0 stock and had grown in the test plantings for 5 to 6 years. These trees were cut, and disks or appropriate-sized wedges from disks were used in the evaluation work. The wood samples were located 16 to 32 inches above the ground and contained only those annual rings that developed after field planting.

Specific gravity determinations were run in duplicate, and the wood samples used for specific gravity were also the source of fibers for the fiber-length measurements. The fiber-length data reported for the 5- and 6-year-old trees were obtained on a ring-by-ring basis for the last three growth rings and were based on approximately 500 fibers from the fifth annual ring. All fibers 0.3 mm and longer including those cut, broken, and intact were measured.

The age-30 fiber-length measurements for the older trees were obtained by dividing the 10-mm increment cores into 5-year intervals, measuring 400 to 500 fibers per 5-year interval, plotting the fiber length-age curve, and taking the age-30 fiber-length value from the curve. For trees that were less than 30 years old, the fiber length for the last 10-year interval was determined and the fiber-length age information was adjusted to age 30, using a previously prepared fiber length-age curve. All fibers 0.3 mm and longer including those cut, broken, and intact were measured.

Information on pulp yield and fiber strength was obtained by micro-pulping small chip samples prepared from increment core or disk samples. Duplicate determinations were made upon the 5- and 6-year-old trees, and single determinations for all other trees. The micropulping procedure used employed a kraft pulping system and a multiunit digester (van Buijtenen *et al.* 1961). The techniques and the cooking conditions employed are reported in detail by Gardner and Einspahr (1964). The data on the percent yield of pulp are based on equivalent weights of wood in each digester. Zero-span tensile strength measurements were conducted on test handsheets, using the procedure described by Wink and Van Eperen (1962), and are interpreted as a measure of individual fiber strength. Alcohol benzene extractives and percent lignin were determined on wood samples using TAPPI standard methods T 6 M-54 and T 13 M-54.

Discussion of Results

Tables 1 and 2 summarize the results of the wood quality evaluation work with aspen and cottonwood carried on over the past 10 years. The greatest amount of evaluation work has been done with specific gravity, and the least number of

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[1] *Respectively, Research Associate, Research Fellow, and Supervisor of the Pulping Laboratory, The Institute of Paper Chemistry, Appleton, Wisconsin.* *The authors wish to acknowledge: the financial support of this work by the Lewis W. and Maude Hill Family Foundation of St. Paul, Minnesota, and the ten pulp and paper companies who are members of the Lake States Aspen Genetics and Tree Improvement Group; the valuable assistance of Mrs. Marianne Harder for making many of the fiber-length and specific gravity measurements and helping to tabulate the data; and the help of Mrs. Susan Lebergen and Mr. W. Wink and members of the Paper Evaluation Group in evaluating fiber length and fiber strength.*

Table 1. — Wood and fiber properties of Lake States-grown Populus *and* Populus *hybrids*

Species[1]	Age, yr.	Specific gravity, g./cc.: Average[3]	Specific gravity, g./cc.: Range	Fiber length, mm.[2]: Average[3]	Fiber length, mm.[2]: Range	Zero-span tensile, lb./in.: Average[3]	Zero-span tensile, lb./in.: Range
P. alba hybrids	18-30	0.392 (2)	0.389-0.394	1.10 (2)	1.00-1.21	--	--
	31+	.358 (4)	.334- .375	.99 (2)	.98-1.00	72.2 (1)	
P. deltoides	18-30	.363 (3)	.357- .372	1.10 (2)	1.05-1.15	--	--
	31+	.352 (10)	.336- .374	.95 (8)	.82-1.05	66.7 (5)	59.0-75.2
P. grandidentata	18-30	.363 (2)	.341- .385	.97 (3)	.94- .99	--	--
	31+	.378 (31)	.325- .433	.97 (40)	.77-1.18	72.9 (5)	67.7-81.8
P. tremuloides (3n)	31+	.391 (34)	.318- .447	1.23 (33)	1.02-1.37	56.9 (23)	48.6-65.9
P. tremuloides	18-30	.390 (123)	.310- .456	.97 (124)	.76-1.20	55.3 (5)	49.3-61.4
	31+	.390 (285)	.331- .476	.93 (283)	.62-1.19	60.5 (66)	49.4-76.7
P. tremuloides	5	.370 (554)	.311- .450	.67 (305)	.46- .94	65.5 (153)	56.2-75.4
P. tremuloides (3n)	5	.362 (72)	.342- .394	.65 (48)	.55- .76	61.8 (24)	56.6-66.5
P. tremuloides x P. tremula (3n)	5	.403 (70)	.347- .481	.75 (48)	.53- .88	61.0 (24)	46.9-77.2
P. tremuloides x P. sieboldii	6	.345 (9)	.318- .366	.72 (4)	.64- .85	61.2 (4)	57.2-64.2
P. tremuloides x P. davidiana	6	.340 (22)	.291- .374	.74 (8)	.70- .84	63.5 (9)	55.2-68.1
P. alba x P. grandidentata	6	.380 (5)	.344- .418	--	--	--	--
P. grandidentata x P. davidiana	6	.345 (12)	.312- .374	.76 (4)	.69- .81	63.7 (3)	60.8-67.2
P. grandidentata x P. alba	6	.373 (9)	.324- .441	.73 (4)	.67- .78	59.0 (4)	55.8-60.4

[1] The P. alba hybrids are naturally occurring hybrids in which the female parent is P. alba and the male parent is believed to be P. grandidentata. 3n indicates trees having three sets of chromosomes (triploids).

[2] Fiber length based on age 30 for mature, natural stand trees, and age 5 for plantation grown trees.

[3] Number in parentheses indicates number of individuals used to obtain the mean and range.

measurements involve lignin and extractive determinations. Comparison of data from wedges from young trees with increment-core data from older trees will tend to reduce slightly the differences between the two types of measurements. The reason is that the core samples weight the center of the tree more than the exterior portion so that the wood samples in this instance are more nearly alike (high in proportion of young wood) than usual.

Specific Gravity

Specific gravity, because of its influence on pulp yield and pulp properties and because it is influenced by cell wall thickness, relative proportion of latewood, proportion of thin-walled vessels, and the presence of reaction wood, is of interest from the tree improvement point of view. The specific gravity data were based on measurements of 1,245 trees. The majority of trees measured were either mature quaking aspen or 5-year-old plantation-grown quaking aspen. Because of the numbers of individuals involved, these data make reliable standards of comparison. Looking first at the mature trees, there appears to be no significant difference between the diploid quaking aspen "age groups" or between diploid and triploid quaking aspen. Bigtooth aspen specific gravity data, although based on fewer trees, seem to indicate that this species may have a slightly lower specific gravity than quaking aspen. It also appears

Table 2. — Pulp and chemical properties of Lake States-grown Populus *and* Populus *hybrids*

Species[1]	Age, yr.	Pulp yield, percent		Lignin, percent		Extractives, percent	
		Average[2]	Range	Average[2]	Range	Average[2]	Range
P. alba hybrids	18-30	--	--	--	--	--	--
	31+	51.5 (1)		20.4 (1)		3.8 (1)	
P. deltoides	18-30	--	--	--	--	--	--
	31+	51.2 (5)	50.5-52.7	22.4 (5)	22.0-22.9	2.1 (5)	2.0-2.2
P. grandidentata	18-30	--	--	--	--	--	--
	31+	51.2 (5)	50.0-52.8	20.3 (5)	20.0-20.6	3.0 (5)	2.7-3.3
P. tremuloides (3n)	31+	55.1 (24)	51.8-59.0	18.3 (24)	16.2-19.9	3.14 (24)	2.38-4.00
P. tremuloides	18-30	51.0 (3)	49.7-52.6	--	--	--	--
	31+	51.8 (61)	47.8-54.4	19.2 (1)		3.5 (1)	
P. tremuloides	5	48.8 (153)	43.6-52.4	18.1 (153)	15.7-20.4	4.64 (153)	2.70-16.7
P. tremuloides (3n)	5	48.2 (24)	46.6-50.2	17.2 (24)	16.6-17.9	6.32 (24)	4.98-7.90
P. tremuloides x P. tremula (3n)	5	48.8 (24)	46.8-50.4	17.2 (24)	16.3-18.2	5.38 (24)	4.76-6.37
P. tremuloides x P. sieboldii	6	48.0 (4)	47.2-48.9	19.3 (4)	18.4-19.8	4.56 (4)	4.30-4.93
P. tremuloides x P. davidiana	6	49.3 (9)	48.0-51.2	18.3 (8)	18.0-18.8	4.64 (8)	4.34-5.18
P. alba x P. grandidentata	6	--	--	--	--	--	--
P. grandidentata x P. davidiana	6	49.3 (3)	48.4-49.8	17.6 (4)	17.2-18.4	4.90 (4)	4.65-5.40
P. grandidentata x P. alba	6	50.1 (4)	49.2-50.7	18.0 (4)	16.9-19.2	4.45 (4)	3.93-4.94

[1] The P. alba hybrids are naturally occurring hybrids in which the female parent is P. alba and the male parent is believed to be P. grandidentata. 3n indicates trees having three sets of chromosomes (triploids).

[2] Number in parentheses indicates number of individuals used to obtain the mean and range.

that the specific gravity of cottonwood and the older *P. alba* hybrids is lower than quaking aspen. Comparison of the younger aged trees (5 and 6 years old) with the mature-tree specific gravity of 0.390 suggests only moderate decreases have resulted despite the relatively young age of the trees involved.

The young triploid hybrids (*P. tremuloides* x *P. tremula* triploid) had the highest average specific gravity of the trees evaluated, and the hybrids between *P. tremuloides* and *P. davidiana* had the lowest specific gravity. The fairly wide range in values reported suggests that the genetic improvement of specific gravity appears to be quite promising.[2]

[2] *Broad sense heritability for specific gravity in aspen has been estimated to be about 0.4 (Einspahr* et al. *1967a, and van Buijtenen* et al. *1962).*

Fiber Length

Fiber length influences a number of pulp strength characteristics and, particularly in the short-fiber hardwoods, longer average fiber length is generally accompanied by higher tear resistance and, to a lesser extent, increases in burst, tensile, and fold (Tappi 1960). Because of the importance of fiber length, parent trees and progeny groups have been evaluated and minimum standards established.

Using the fiber length of diploid quaking aspen (table 1) as a standard of comparison, it appears that bigtooth aspen, quaking aspen, and cottonwood have similar age-30 fiber lengths. Triploid quaking aspen has a fiber length approximately 28 percent longer than the native diploid species

mentioned above. The data for *P. alba* hybrids are too limited to judge adequately the fiber length of this material, but preliminary measurements indicate it is at least as good as that of the native quaking aspen.

The age-5 fiber lengths are, as expected, less than the age-30 fiber measurements. The several aspen hybrids all had average fiber lengths exceeding that of the diploid quaking aspen.

An earlier reported comparison of the age-5 fiber length of the triploid hybrids confirmed its superiority over that of diploid quaking aspen (Einspahr *et al.* 1967b). Despite the restricted number of measurements on the other hybrids, the fifth-year fiber length of several of the materials suggests that these hybrids can be expected to have fiber lengths longer than those of the native aspen. It is also of interest that the fifth-year data reported are approximately equal to the fiber-length averages reported for mature maples. Pulping work with these young aspen and aspen hybrids indicates they will yield pulps satisfactory for the types of papers presently being made from quaking aspen.

Zero-Span Tensile Strength

Zero-span tensile strength is a difficult measurement to make but when properly handled gives an average fiber strength value. Zero-span tensile strength has been shown to be positively related to the more conventional paper tests of burst, tear, and tensile strength and has the advantage that it can be made on a very limited amount of pulp. Because the absolute values obtained are influenced by cooking conditions, sheet formation, and other processing variables, fairly large differences (8 to 10 lb/in.) must exist between the averages in order for the differences to be meaningful.

Based upon earlier experience (Gardner and Einspahr 1964) with this test it seems unlikely that the zero-span tensile strength differences for the 5- and 6-year-old trees are statistically significant. Comparing the fiber strength of the older trees, bigtooth aspen and possibly cottonwood appear to have fiber strength values greater than diploid quaking aspen. A comparison of the young trees with the older trees reveals that the 5- and 6-year-old trees have higher zero-span tensile strength values, although it is doubtful that the differences presented are statistically significant.

Lignin, Extractives, and Pulp Yield

Because of the interrelationships between levels of lignin, extractives, and yield of pulp, these factors are considered together (table 2). Differences between types of materials in the above properties were not large except for the older triploid quaking aspen, which had the highest average pulp yield and relatively low levels of lignin and extractives. The 5- and 6-year-old trees had 2 to 3 percent lower pulp yield than the older bigtooth and quaking aspen. This reduced yield apparently resulted from the higher extractive levels present in the younger aged trees. Lignin levels in the younger trees were 1 to 2 percent less than in the older trees, but despite this lower level of lignin the overall pulp yields were less. The pulp yield and extractive and lignin levels for the younger aged trees are surprisingy uniform considering the differing genetic parentage. The somewhat reduced overall natural variation in the above chemical properties of aspen suggest that only limited gains can be expected if these properties are emphasized in tree improvement work.

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TRACHEID DEVELOPMENT AND WOOD QUALITY IN LARCH SEEDLINGS UNDER CONTROLLED ENVIRONMENT

J. J. Balatinecz and J. L. Farrar[1]

Several environmental factors necessary for tree growth undergo rhythmic and sometimes abrupt changes during the course of a year, and even during a day. Since wood cells are susceptible to outside influences during their differentiation, certain fluctuations of environmental conditions invariably leave a permanent imprint on xylem anatomy, and hence significantly influence wood quality. Such features as the width of annual increments, cell length, cell diameter, cell wall thickness, and the development of drought and frost rings are affected by environmental factors to some degree. The effects of environment on xylem differentiation may be either direct or indirect, since xylem differentiation is integrated with other physiological processes in the living tree (e.g., photosynthesis, respiration, translocation) which are also subject to environmental influences.

In addition to genetic selection and breeding for desirable wood quality features, the manipulation of environmental factors (e.g., through irrigation, fertilization, and other silvicultural practices) offers man a limited but nevertheless important tool to influence the anatomy of developing wood cells, and hence wood quality. However, this can only be accomplished successfully if the inter-relationships between wood formation and environment are understood.

The effects of photoperiod on wood formation have been investigated extensively in recent years (Larson 1960, 1962, 1964; Phillips and Wareing 1958; Nitsch 1963; Wodzicki 1960, 1961, 1964). The current consensus is that photoperiodic effects on xylem differentiation are indirect, and are mediated by growth regulating substances. Long photoperiods are associated with intense cambial activity and earlywood differentiation, while short photoperiods favour latewood differentiation and eventual cambial quiescence. Under long days, the synthesis of auxins, gibberellins, and auxin synergists, which are generally regarded as growth promoters, is at a high level, while the synthesis of growth inhibitors is at a low level. The effect of short days on the metabolism of the above substances, on the other hand, appears to be opposite.

The effects of precipitation and the resulting soil and internal moisture conditions on wood formation have also been studied (Kennedy 1961; Kramer 1962, 1964; Larson 1963; Zahner 1963; Zahner *et al.* 1964; Edlin 1965; Buckingham 1965). Two hypotheses were developed to explain the influence of internal water stress on wood formation at the cellular level. According to the first view, water deficit has a direct effect on xylem development, in that a decreased turgor pressure may reduce the enlargement of differentiating xylem cells. The number of cambial divisions may also be reduced. According to the second view (Larson 1963), the effect of drought on xylem development is indirect. Water deficits first reduce the growth of terminal meristems and leaves which results in decreased auxin synthesis. The decreased auxin supply brings about the differentiation of latewood cells. Kramer (1964) and Zahner (1963) both emphasized that both the direct and indirect effects of water deficits were important in xylem development. The water balance of differentiating xylem cells influenced not only their enlargement but also their metabolism. Furthermore, water deficits reduced photosynthesis, and thereby the supply of carbohydrates. Kennedy and Farrar (1965) observed that drought caused subnormal lignification in tilted seedlings.

Reports about the influence of temperature on wood formation are relatively few. The available studies nevertheless suggest that temperature plays a very important role in wood formation. Richardson and Dinwoodie (1960) found an inverse relationship between cell wall thickness and night temperatures. Tracheid length and lumen diameter, on the other hand, increased with increasing temperatures, either day or night. They suggested that cell wall thickening was a function of net assimilation rate, which apparently dropped with increasing night temperatures.

Many of the aforementioned results were derived from experiments with seedlings because seedlings are easily obtained and subjected to various treatments. Most conclusions concerning basic physiological processes have general validity; however, many investigators caution against broad generalizations and unreserved interpretation of results for forest-grown trees.

This study examines certain effects of two different photoperiods on the initiation of cambial activity and subsequent xylem development in inactive and actively growing eastern larch (*Larix laricina* (DuRoi) K. Koch) seedlings; explores some influences of mild, intermediate, and severe drought conditions on xylem development; and

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evaluates certain effects of synthetic IAA and TIBA on xylem differentiation under short and long photoperiods, respectively.

Materials and Methods

Two-year-old nursery transplants of 132 eastern larch seedlings 40 to 60 cm tall and 5 to 8 mm in diameter at stem base were studied. The seedlings were transplanted into individual 500 ml containers, using Perlite rooting medium. The rooting medium was subirrigated with complete nutrient solution three times daily. The investigation was carried out in three phases.

Photoperiodic Treatments

First, the effects of two photoperiods (short days and long days) on the initiation of cambial activity and on subsequent xylem differentiation were studied in 96 seedlings. These seedlings were sub-divided into seven groups and exposed to either short days (SD), long days (LD), or both, for 12 weeks:

Group[1]	*No. of weeks exposed to—* SD	LD	*Number of seedlings*
1 (IC)	7	5	12
2 (IC)	0	12	10
3 (AC)	0	12	12
4 (AC)	12	0	24
5 (AC)	3	9	16
6 (AC)	5	7	12
7 (AC)	7	5	10

[1] IC = Inactive cambium at start of treatment; AC = Active cambium.

The short photoperiods were provided in a growth chamber regulated for 10-hour day length, 1,500 ft-c light intensity, and temperatures of 25° C day and 15° C night. Long photoperiods were provided in a greenhouse, where sunlight was supplemented with artificial illumination to obtain a 16-hour day length. Temperatures in the greenhouse ranged from 25° to 29° C during the day, and from 15° to 19° C during the night.

The cambia of seedlings in Groups 1 and 2 were inactive (IC) at the commencement of photoperiodic treatment. These seedlings had their winter chilling requirements met outdoors. However, the seedlings in Groups 3 to 7 had been actively growing (AC) and forming earlywood prior to treatment due to long-day exposures. Thus it was necessary to demarcate the commencement of treatment in these seedlings. All seedlings in Groups 3 to 7 were tilted for 3 days at 60° from the vertical, then put upright for 6 days, and again tilted for 3. This method had been employed by Kennedy and Farrar (1965) to produce two compression-wood marker arcs.

During the 12-week photoperiodic treatment the height growth of seedlings was determined at weekly intervals. At the same time the condition of apices, the appearance of needles, and the setting of resting terminal buds were observed.

The sampling schedule is outlined in table 1. From each seedling three stem pieces, approximately 2 cm long, were excised at 2, 10 and 20 cm from the stem base (lower, middle, and upper stem, respectively), and aspirated in FAA solution. Transverse sections were cut on a sliding microtome and stained by the safranin-fast green technique. All sections were examined microscopically for the pattern of xylem differentiation that accompanied the photoperiodic treatments. The radial and tangential diameters, and tangential double-wall thicknesses of all tracheids (matured after the commencement of treatment) were measured in five typical radial files. These measurements were taken only on sections from the middle stem of the 16 seedlings sampled at the end of 12 weeks. The radial files measured were selected on the basis of maximum tangential diameters to assure that tracheids in the files were cut close to their midlength. The values of tracheid diameters and wall thickness were used to calculate three indices. The cell enlargement index (CEI) was defined as the ratio between the radial (r) and tangential (t) diameters of the cell (r/t). The wall thickness index (WTI) was defined as the ratio between the tangential double-wall thickness (2w) and the tangential diameter (t) of a tracheid (2w/t). The specific gravity index (SGI) was defined as the ratio between the tangential double-wall thickness (2w) and the radial diameter (r) of a tracheid. Since tangential tracheid diameters vary but little from early- to latewood, the r/t and 2w/t ratios directly express the degree of radial enlargement and wall thickening, respectively. A CEI of 0.90 may be used as an arbitrary boundary between early- and latewood rather than Mork's index, which has been criticized by tree physiologists because it confounds wall thickness and radial lumen diameter, two cell features which may vary independently of one another.

Drought Treatments

Twenty actively growing, 2-year-old eastern larch seedlings were divided into four groups, with five seedlings in each group, and exposed to different watering conditions for 3 weeks. All seedlings were tilted prior to treatment, in a manner described previously, to induce two compression-wood marker arcs. One group was exposed to "mild" drought (200 ml water every 5 days), another to "intermediate" drought (100 ml water every 5 days), and another to complete drought (no water). The controls received normal watering by subirrigation. After a 3-week-long drought exposure, normal watering was resumed for all

Table 1. — Sampling schedule for the seedlings

Group	Sampling time (weeks after commencement of treatment)											
	1	2	3	4	5	6	7	8	9	10	11	12
	Number of seedlings sampled											
1	–	–	2	–	2	–	2	–	2	–	–	4
2	–	–	2	–	2	–	2	–	2	–	–	2
3	2	–	2	–	2	–	2	–	2	–	–	2
4	2	2	2	2	2	2	2	2	2	2	2	2
5	–	–	–	2	2	2	2	2	2	2	–	2
6	–	–	–	–	–	2	2	2	2	2	–	2
7	–	–	–	–	–	–	–	2	2	2	2	2

seedlings, and they were grown for an additional 5 weeks. During the entire 8 weeks the seedlings were in a greenhouse under long (16-hour) days. At the end of 8 weeks three stem pieces were excised from each seedling, sectioned, stained, and evaluated microscopically the same way as the samples from the photoperiodic experiments. The external responses of seedlings were also observed.

Treatments With IAA and TIBA

Sixteen actively-growing, 2-year-old eastern larch seedlings were divided into four groups, with four seedlings in each. Two groups (8 seedlings) were exposed to short days (10-hour) for 3 weeks to induce latewood formation, while the other two groups were tilted in the earlier described manner to induce two compression-wood marker arcs. One group (4) of the SD seedlings was treated with IAA, and one group of the LD seedlings was treated with TIBA in the following way. The dead outer bark was removed on a 2-cm portion of the stem of each seedling at a distance 10 cm from the stem base. Three shallow longitudinal blazes were cut into the inner phloem, each at 120° angle from the other, and extending to, but not beyond, the cambium. Immediately after the blazes were cut, the exposed surfaces were sprayed with distilled water. Then a single paper strip (3 sq cm), containing 50 micrograms of IAA or TIBA (50 micro-liters of 1000 ppm solution), was moistened with distilled water and placed over the inner phloem surface. The outer surface and edges were covered with lanolin, which was further covered with a dark masking tape. Controls of both SD and LD groups were also treated but the paper strip did not contain any compound. The SD seedlings remained in the growth chamber, while the LD seedlings were kept in the greenhouse for 3 weeks following treatments. At the end of 3 weeks, three stem pieces 2 cm in length were excised from each seedling, one immediately below the blaze, a second and third at 2 and 4 cm respectively below the blaze. The stem pieces were sectioned, stained, and examined microscopically, as described previously.

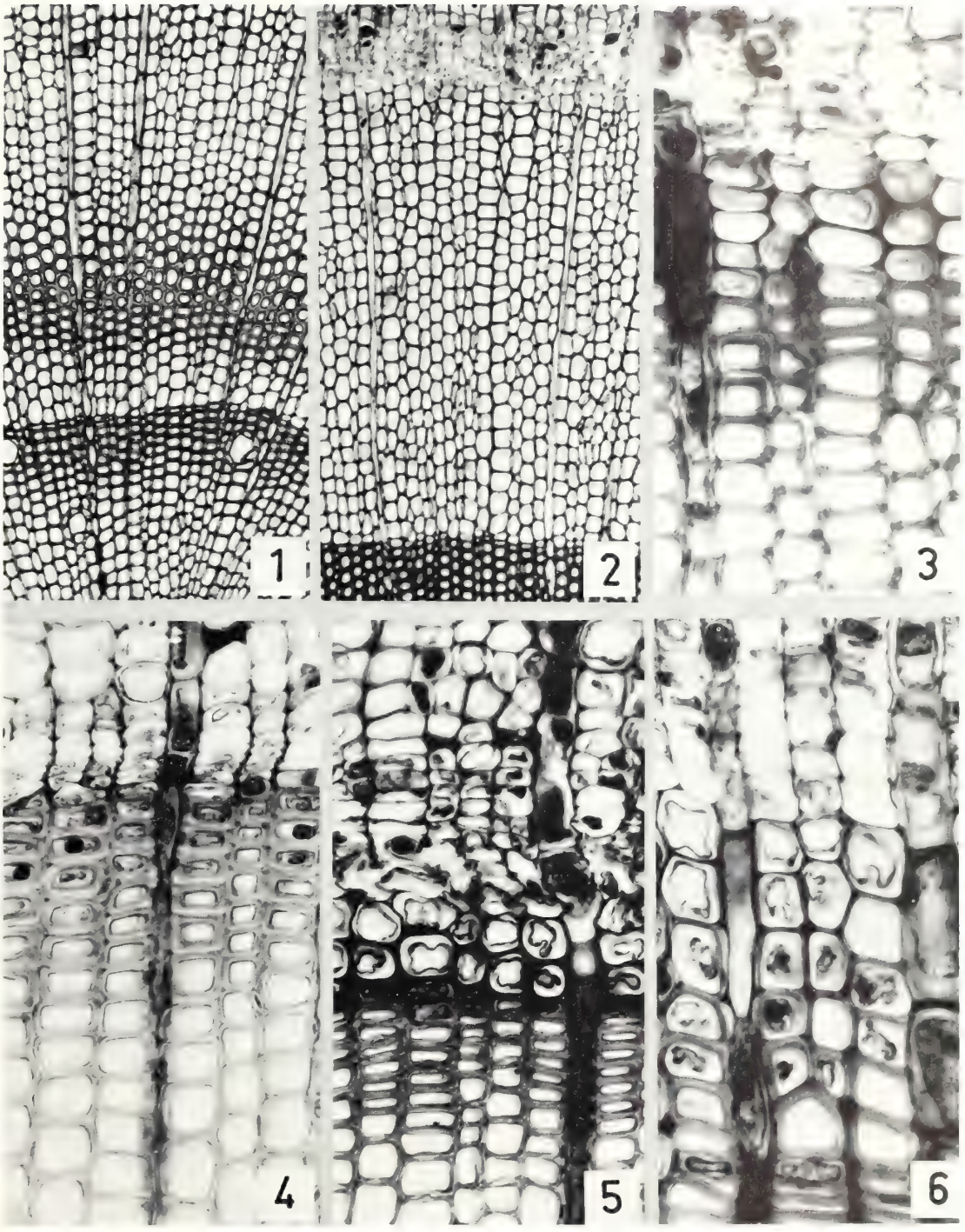
Results and Discussion

Photoperiodic Treatments

Growth activity in the buds and cambium of the seedlings in Groups 1 and 2 occurred under both short and long days. The buds of seedlings in Group 1 (initial SD) began swelling around the twelfth day, whereas those in Group 2 (LD) began around the ninth day. The growth of the new needles on the short shoots was nearly completed by the end of the third week in both groups; this coincided with the commencement of long-shoot extension and cell division in the cambial zone. However, by the end of the fifth week the SD seedlings were forming a terminal bud, and their average shoot growth (4.6 cm) was only half that of LD seedlings for the same period. The LD seedlings continued unabated shoot extension growth during the entire 12 weeks.

Swelling of the cambial zone occurred in both Groups 1 and 2 by the third week, indicating that this phase of cambial activity is not a photoperiod-dependent phenomenon, but rather correlated with temperature. Cell division in the cambial zone commenced around the end of the third week, coincidentally with rapid shoot extension, indicating a correlation and dependence of cell division in the cambial zone on endogenous auxins originating in active apical meristems.

The first-matured tracheids had CEI greater than 0.90 (earlywood) in the seedlings of both Groups 1 and 2 (figs. 1 and 2). The average CEI of the first 3-4 cells per radial file was 1.09 in both groups (fig. 7). However, the SD seedlings (Group 1) formed a narrow band of latewood cells (CEI less than 0.90), coincidental to the cessation of shoot extension (figs. 1 and 7). The formation of 3-4 earlywood tracheids per file under short days may seem surprising, but it took place during the short period of shoot extension growth when endogenous auxins were available in sufficient amounts to facilitate earlywood differentiation. The effects of short days only became apparent after the development of the photoreceptive organs (leaves).



FIGURES 1 to 6. — The pattern of xylem differentiation and tracheid anatomy in larch seedlings under different photoperiods (IC — inactive cambium, AC — active cambium, at commencement of treatment.

(1) Group 1, IC, 7 weeks SD plus 5 weeks LD, lower stem.
(2) Group 2, IC, 9 weeks LD, lower stem.
(3) Group 4, AC, 3 weeks SD, middle stem.
(4) Group 4, AC, 4 weeks SD, lower stem.
(5) Group 5, AC, 3 weeks SD plus 1 week LD, lower stem.
(6) Group 5, AC, 3 weeks SD plus 2 weeks LD, lower stem.

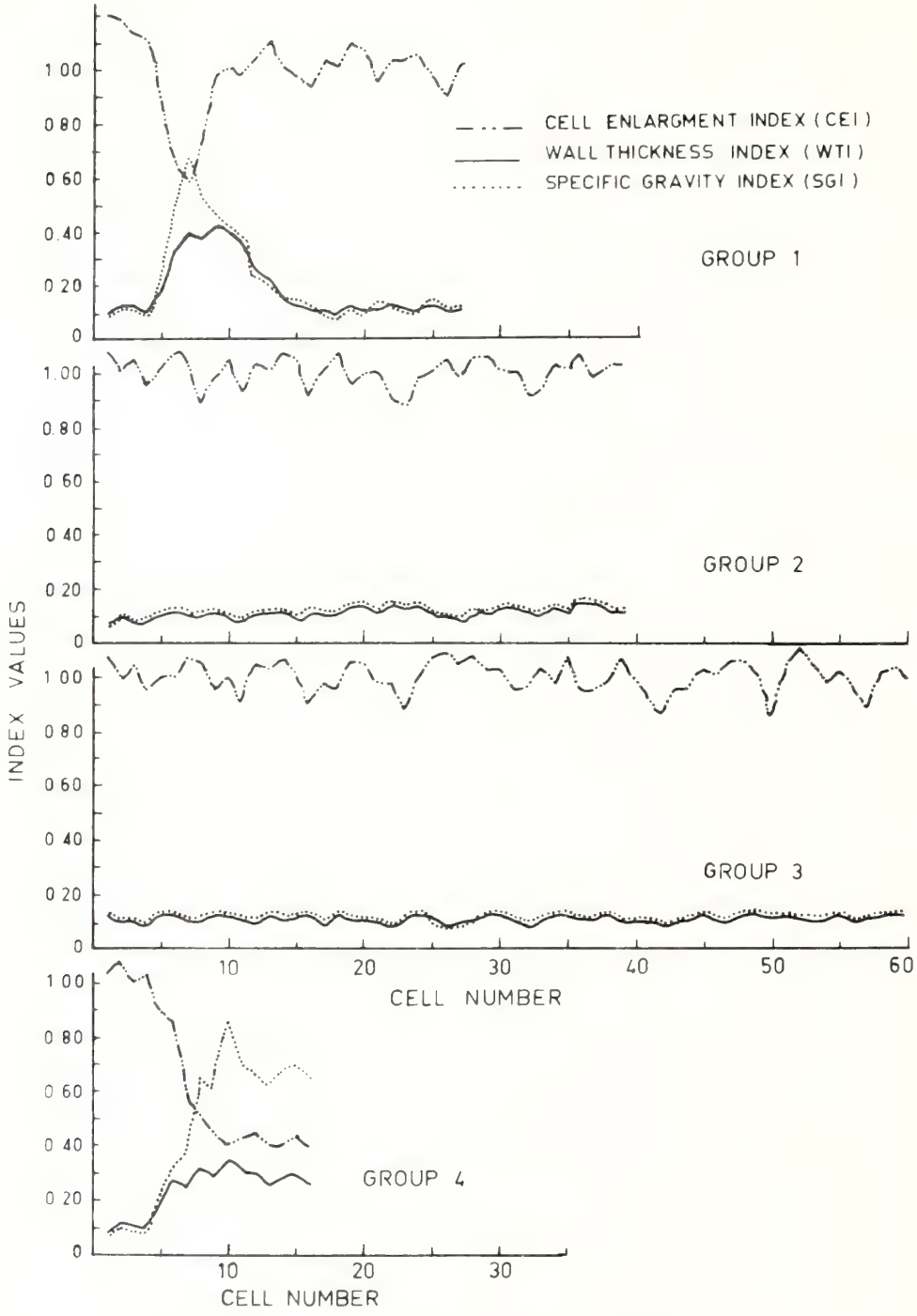


FIGURE 7. — The variation of CEI, WTI, and SGI in the middle stem of seedlings in Groups 1, 2, 3, and 4.

The narrow latewood band (3-4 tracheids per file) in SD seedlings was followed by a band of compression-wood like tracheids (4-5 per file), which apparently formed after the seedlings were transferred to long days at the end of 7 weeks (fig. 1). The formation of this compression wood band was an interesting physiological development. We offer the following explanation. The SD treatment lowered endogenous auxin levels in the seedlings, which was fairly abruptly increased after the seedlings were transferred to long days. Thus the relative increase of auxin facilitated the

development of compression wood. Compression wood development ceased to continue because the cambium and differentiating cells became "accustomed" to the change.

The actively growing seedlings of Groups 3 to 7 also showed some interesting responses to the photoperiodic treatments. The LD control seedlings (Group 3) continued height growth during the entire 12 weeks. The seedlings in the other groups, which were exposed to various periods of SD treatment, showed reduced extension growth after the second week, and were forming resting terminal buds by the end of the third week of short photoperiod.

The seedlings in Groups 5, 6, and 7 were transferred to long days at the end of the third, fifth, and seventh weeks, respectively. The inactive buds in Group 5 began flushing within the first 2 weeks of LD treatment, whereas those in Group 6 began during the third and in Group 7 during the fourth week of LD treatment. The seedlings in Groups 5 and 6 kept their old foliage; however, those in Group 7 lost most of their needles prior to transfer.

The periodic samplings of two seedlings during the treatment, and of two seedlings at the conclusion of treatment (table 1) allowed the assessment of the progress and possible changes in xylem differentiation. In Group 3, earlywood differentiation continued during the entire 12 weeks. There were 73 fully mature tracheids per file in these seedlings, and only minor variations occurred in CEI, WTI, and SGI of tracheids in the radial files (fig. 7). In Group 4 (SD controls), there were only 16 mature tracheids per file at the end of 12 weeks; 10 of these had CEI less than 0.90. Short days caused a reduction in the rate of cell division by the end of the first week, and cell division almost ceased by the third week. The CEI of enlarging tracheids was also reduced between the first and third weeks, while WTI and SGI were increased during the same period (fig. 7). Between the fourth and fifth weeks of SD treatment the cambium became quiescent (fig. 4).

All seedlings in Groups 5, 6, and 7 also formed a band of latewood, since they were all exposed to at least 3 weeks of SD treatment. However, there were differences in the response of these three groups to long days. The seedlings in Group 5, which received only 3 weeks of SD treatment, continued cambial division and xylem differentiation within the first week of LD treatment (fig. 5) and thereafter at a relatively rapid pace (fig. 6). The seedlings in Group 6 recommenced cambial division and xylem differentiation during the second week of LD treatment (fig. 9), while those of Group 7 recommenced during the third week. At the end of 12 weeks, there were 61, 44, and 35 fully mature tracheids per file in Groups 5, 6, and 7, respectively. The variation in CEI, WTI, and SGI of mature tracheids in these latter three groups is shown in figure 8. The CEI of the first 4-5 tracheids per file which matured under long days showed a gradual increase in Groups 5 and 6 (fig. 10), and an abrupt increase in Group 7 (fig. 11). Also, the WTI and SGI showed a gradual decrease in Groups 5 and 6, but an abrupt decrease in Group 7. These differences were probably due to the presence of old needles in Groups 5 and 6, and their absence in Group 7.

The foregoing results confirmed that photoperiod plays a decisive role in the regulation of cambial activity and subsequent xylem differentiation. Short days alone were sufficient to bring about the differentiation of tracheids with low CEI (latewood). Larson (1962, 1964) and Wodzicki (1961, 1964) made similar observations for coniferous seedlings. The effects of photoperiod on xylem differentiation are believed to be mediated by endogenous growth-regulating substances.

Drought Treatments

Wilting of different magnitudes accompanied the various drought treatments. The seedlings under complete drought were affected the most; three out of four died before the completion of treatment. The seedlings under both "mild" and "intermediate" drought wilted in between the 5-day watering intervals, and lost 40 to 70 percent of their foliage by the end of the drought exposure. Three of the five seedlings under "mild" drought and all five under "intermediate" drought formed resting terminal buds by the end of drought treatment. The controls continued height growth throughout the entire period of treatment.

Drought also interfered with cell division in the cambial zone and all phases of xylem differentiation. All three drought treatments were severe enough to "check" several tracheids in the various phases of differentiation (i.e., to cause the death of tracheids prematurely). Thus there were 2-3 tracheids per file with subnormal lignification; as many as 5-6 tracheids were checked in wall thickening; and 4-8 tracheids were checked in the phase of enlargement. This pattern indicates the direct effect of drought on tracheid development. A similar scheme was observed by Kennedy and Farrar (1965) in jack pine (*Pinus banksiana* Lamb.) seedlings.

Drought also interrupted the growth of apical meristems and needles, which in turn reduced endogenous auxin levels and facilitated the differentiation of a relatively wide band of latewood tracheids (fig. 12). This development prevailed for some time after the resumption of watering, and illustrated the indirect effects of drought on xylem development. Larson (1963) proposed that drought directly influenced the growth of the terminal meristems, and only indirectly the tracheid diameter through the intermediate action of auxin. Kramer (1964) and Zahner (1963) emphasized that both the direct and indirect effects of

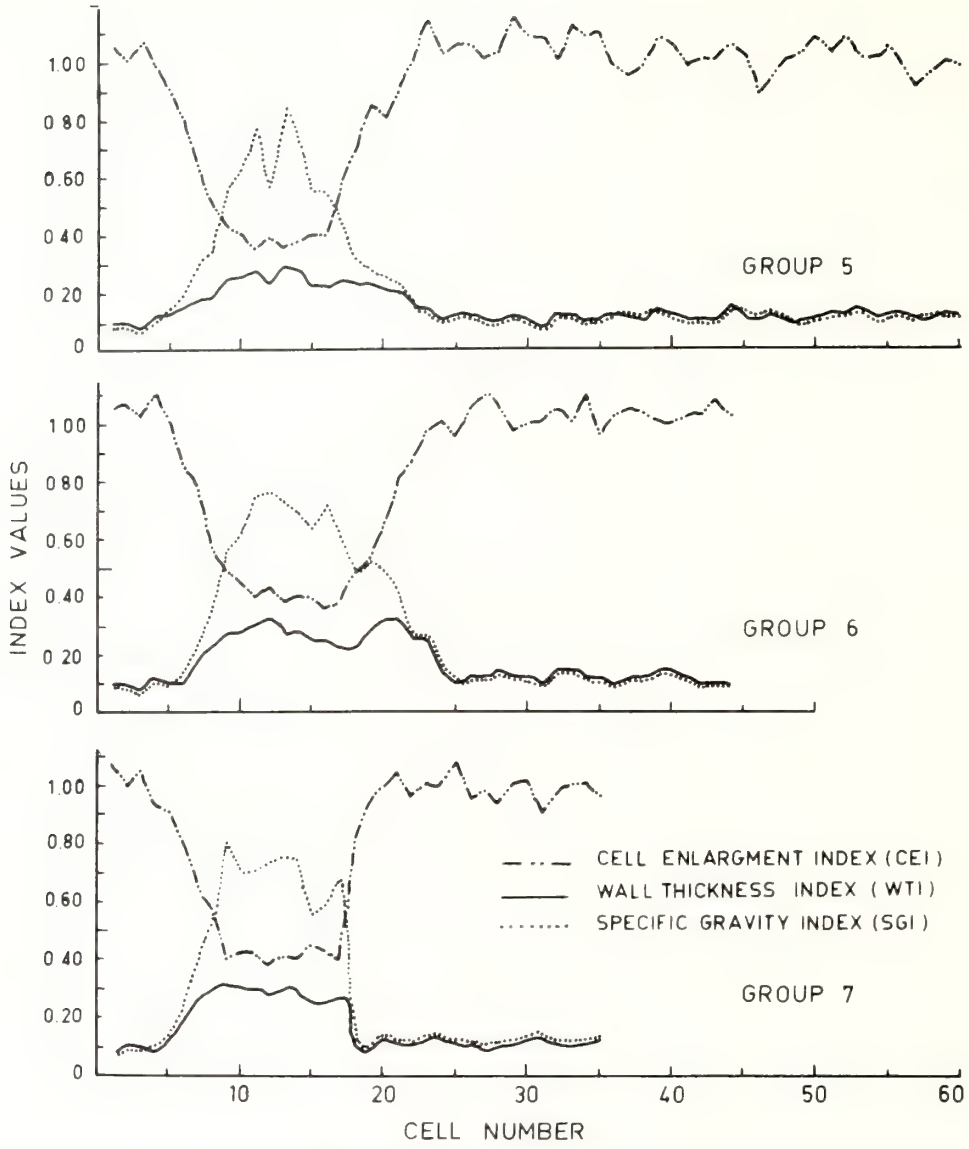


FIGURE 8. — The variation of CEI, WTI, and SGI in the middle stem of seedlings in Groups 5, 6, and 7.

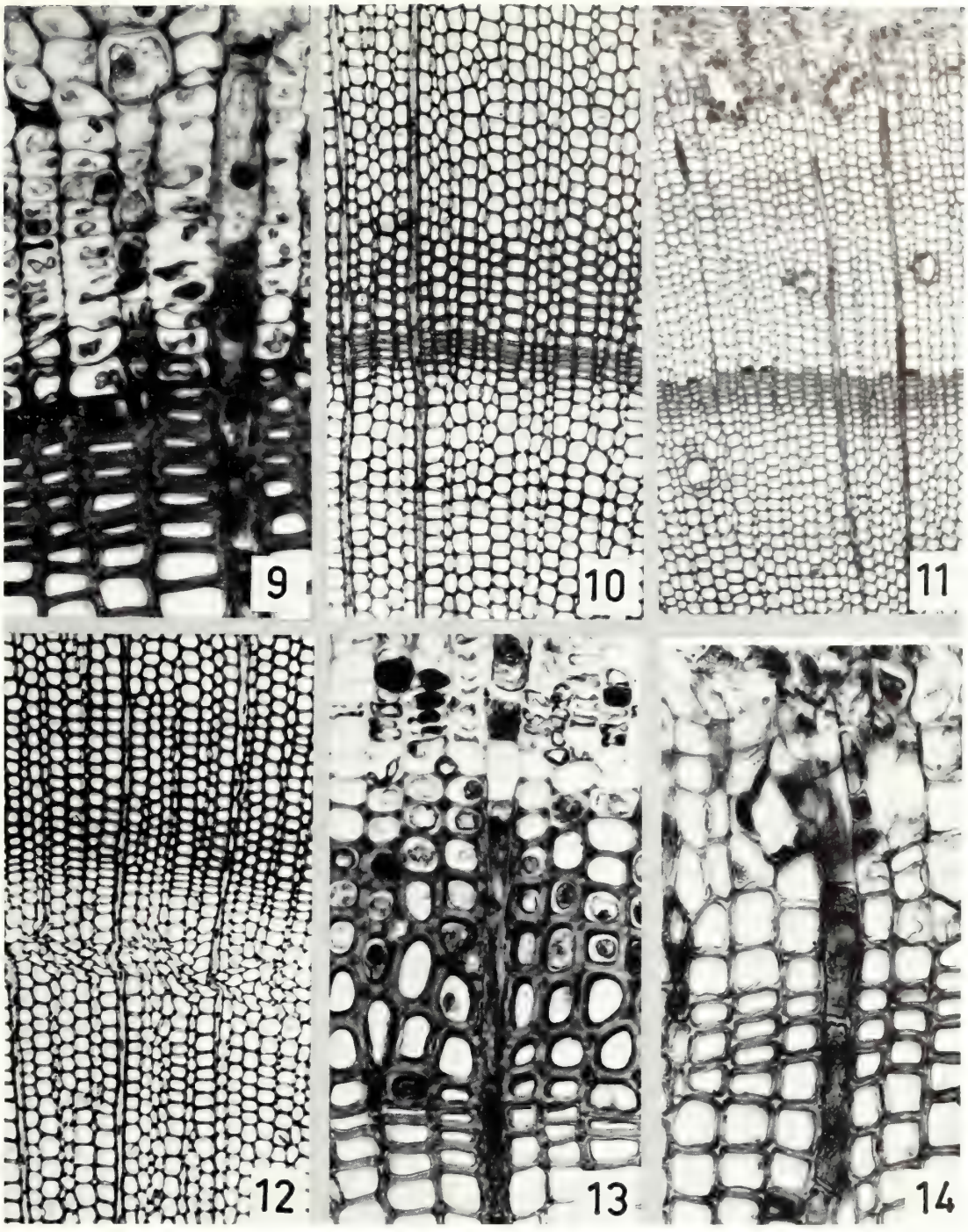
water deficits were important in xylem development.

Treatments With IAA and TIBA

The 3-week exposure to short days, prior to IAA application, facilitated a reduction in CEI and an increase in WTI. In fact, the control seedlings became quiescent by the fourth week. However, the IAA-treated SD seedlings resumed a limited number of cell divisions and continued xylem differentiation (fig. 13). The CEI of newly differentiated tracheids showed considerable increase (greater than 0.90) and their WTI remained fairly high (about 0.25). The newly differentiated tracheids had slightly excessive lignification (characteristic of reaction wood). The growth-stimulating effect of IAA was strongest immediately below the site of application; it was less at 2 cm below, and no apparent effect was present at 4 cm below the blaze.

These results indicated that the SD treatment lowered the level of endogenous auxins sufficiently, first, to cause latewood differentiation and eventually cambial quiescence. However, synthetic IAA could successfully be substituted to reverse this trend temporarily.

The treatment of actively growing LD seedlings with the inhibitor TIBA significantly reduced the enlargement (CEI) of 4-5 tracheids per radial file (fig. 14), while LD controls continued forming



FIGURES 9 to 14. — The pattern of xylem differentiation and tracheid anatomy in larch seedlings under different photoperiods, drought exposure, and treatment with synthetic IAA and TIBA.

(9) Group 6, AC, 5 weeks SD plus 2 weeks LD, lower stem.
(10) Group 6, AC, 5 weeks SD plus 7 weeks LD, lower stem.
(11) Group 7, AC, 7 weeks SD plus 5 weeks LD, lower stem.
(12) The effect of "mild" drought on tracheid anatomy. The "direct" effects of drought are seen in the band of thin-walled, collapsed tracheids, immediately followed by thin-walled tracheids with narrow radial diameters. The "indirect" effects of drought are seen in the following zone of thick-walled tracheids with narrow radial diameters, which formed following drought while the seedling had resting terminal buds.
(13) The effect of IAA treatment on xylem differentiation and tracheid anatomy in an SD larch seedling.
(14) The effect of TIBA treatment on xylem differentiation and tracheid anatomy in an LD larch seedling.

earlywood. It is probable that TIBA, an auxin antagonist, interfered with auxin action during the enlargement phase of tracheid differentiation. Larson (1964) was also able to induce the formation of narrow-diameter tracheids in young red pine growing under long photoperiods.

Summary and Conclusions

Results of this experiment are in agreement with the concept that certain anatomical and hence wood quality characteristics of mature tracheids are determined during differentiation. Photoperiod, water availability, and treatments with synthetic IAA and TIBA all affected the degree of radial enlargement, wall thickness, and hence specific gravity of mature tracheids. Short photoperiods, water deficits, and treatment with TIBA favoured the differentiation of tracheids with low cell enlargement index (i.e., CEI less than 0.90 or latewood), while long photoperiods, adequate water supply, and treatment with IAA favoured the differentiation of tracheids with high cell enlargement index (i.e., CEI greater than 0.90 or earlywood).

The results fitted the theory of limiting factors, i.e., a factor which falls below an optimal threshold will set the pace for physiological events which affect the differentiation of tracheids. Thus, short days alone were sufficient to bring about latewood differentiation, as were water deficits and treatment with TIBA. These observations may have some practical significance. Therefore, in any treatment of forest stands which aims to affect tree growth and wood quality (e.g., irrigation, fertilization, thinning), all environmental conditions should be assessed before treatment is made. The treatment may be wasted or will fail to produce the expected results if one single important environmental factor (e.g., photoperiod) is below a growth-limiting threshold.

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WALNUT WOOD CHARACTERISTICS IN RELATION TO SOIL-SITE CONDITIONS

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It takes little scanning of "Timber Trends in the United States" (U.S. Forest Service 1965) to realize that the hardwood timber of our country needs a great deal of improvement. About 27 percent of the total growing stock of the Nation is hardwoods, 90 percent of the hardwoods are eastern species, and most of them are of poor quality.

But, where does one start to improve the quality? The silviculturist can thin, weed, and prune to improve log quality but what is the effect on intrinsic quality. The geneticist may want to improve the resource, but he must first know the qualities desired, including those of intrinsic wood quality.

For the softwoods, wood quality has long been characterized by wood density. However, the uses of softwoods are generally restricted to engineering and pulp applications, where wood density is important. Hardwoods, on the other hand, have so many diverse applications that wood density loses its importance for most of them.

What then can be used as an indicator of intrinsic wood quality for the hardwoods?

A quick survey of the uses of the various hardwood species certainly gives some indication as to desired qualities. Brown *et al.* (1949) list 49 hardwood species and their uses. Furniture is the largest use, followed by millwork, veneer, and cabinetwork. Other major uses are woodenware, novelties, gunstocks, and flooring.

The first quality consideration for all of these uses is what we would call aesthetics (primarily color). Other quality considerations are texture, shrinkage, machinability, hardness, and strength properties (principally toughness).

With these quality criteria in mind the Forest Products Laboratory, in cooperation with the North Central Forest Experiment Station, initiated a study to evaluate the intrinsic wood quality of black walnut (*Juglans nigra* L.) This work was boosted by the push for increased information on black walnut after the recent symposium on walnut culture (U.S. Forest Service 1966).

This paper is a report on how we are attempting to find a quality criterion for walnut and possibly for other hardwoods. We present no results, just a fresh idea!

[1] *Research Forest Products Technologists, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.*

The Black Walnut Problem

The buyers of black walnut have long shown a preference for logs from certain areas. The reasons for this are not definitely known, although several theories have been advanced. Some claim, and with good cause, that defects such as bird peck, shake, and poor tree form are the main reasons for discrimination. These defects may be more prevalent on trees growing near the borders of the geographical range of the species or on poor sites. On the other hand, some think that discrimination by buyers of walnut logs from certain localities is from habit and without valid reason.

To investigate the possible reasons for such discrimination and to evaluate some measures of intrinsic wood quality, the study objectives became, specifically, to determine whether valid differences occur in the wood characteristics and wood properties of trees growing at various locations under different conditions.

The study is to determine whether differences exist in color and extractives, in anatomical features, and in physical and machining properties of wood. Then, if these differences exist, how do they relate to each other and to site?

The study is divided into three sections: Section I to investigate the color, extractive content, and heartwood-to-sapwood ratio of sample material as a measure of aesthetic quality; Section II to evaluate anatomical characteristics as a measure of texture and shrinkage; and Section III to evaluate the physical and machining properties. All three sections will be related to soil properties.

To provide meaningful results, material was selected from fast- and slow-grown trees from good and poor sites. Specifically, material was selected from two general areas, in Indiana and Missouri. The Indiana locations are considered to represent the best growth areas for walnut, while the Missouri locations are generally regarded as inferior.

Sample Material Selection and Handling

Selection of Sample Trees

The selection of suitable trees for analysis was coordinated through the North Central Forest Experiment Station. Station personnel[2] were responsible for obtaining logs through industrial cooperators in Indiana, and National Forests in Missouri.

[2] *Special acknowledgement is due F. B. Clark, Carbondale, Ill.; R. D. Williams, Bedford, Ind.; and N. F. Rogers, Salem, Mo.*

Thirty-two trees were selected to cover the following stand-site combinations:

	Number of trees	
	Missouri	*Indiana*
Good site:		
Slow growth	4	4
Fast growth	4	4
Poor site:		
Slow growth	4	4
Fast growth	4	4
	16	16

Soil Sampling

At the location of each sample tree, soil samples were taken for correlation with wood properties. A composite 6-inch surface sample was taken at random points around each stump to a distance of 20 feet radially. The composite consisted of 8 borings. At two of the eight points, bulk density samples were also taken. These samples are being analyzed for chemical constituents, organic matter, pH, and physical properties.

To classify each soil on which trees were located, a pit was dug. The soils of this pit were classified and subsoil samples were taken for physical analysis.

Sample Bolts

From each of the 32 selected trees, one 5-foot bolt was taken from the 8- to 13-foot portion. These bolts were inspected carefully and all defects and blemishes on the bolt faces and ends were recorded before sawing.

The ends of each bolt were squared and a disk cut for determination of ring count and sapwood width. These disks are being retained intact for future reference.

Eight or more boards were cut from each bolt and numbered systematically, starting with the board whose face was cut first. Numbering of other boards followed the pattern shown in figure 1.

The sawing method for each bolt was marked on the small end, using a template guide. Each board was flat sawn, 1¼ inches thick, 4¼ inches wide, and 4½ feet long, and has heartwood on at least one face. Sawing was done parallel to the outer surface (bark) in an attempt to keep the same growth rings throughout the board.

Selection of Test Samples

Eight boards from each bolt are being used. Random selection was utilized when more than eight boards were sawed from a bolt.

After planing to a uniform 1⅛-inch thickness, each selected board was marked off into four 1-foot samples (fig. 2) starting at the end corresponding to the top of the bolt, and numbered consecutively. One of the four 1-foot samples was selected randomly, and a 6-inch-long piece was added to the bottom end making, in total, an 18-inch piece.

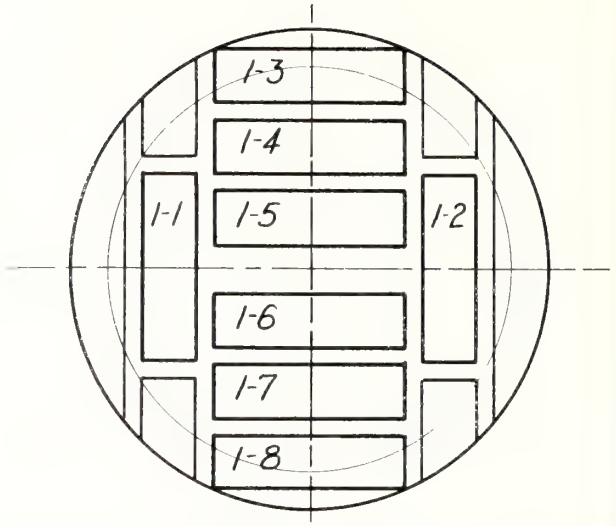

FIGURE 1. — Location of and numbering sequence for boards in the log.

The 18-inch piece was further cut into 6- and 12-inch portions. The 6-inch piece is being used in Sections I and II of the study, while the four 1-foot samples are being used in Section III.

The 6-inch piece was further processed as follows. It was sanded to a uniform 1-inch thickness; each tangential face was then divided into 8 units, ¾ inch long, 1 inch wide, and 3/16 inch thick on the butt end (a total of 16 units per piece) as shown in figure 3. These are being used in the color, extractive, and specific gravity determinations (Section I) and for the anatomical determinations (Section II).

Further sample breakdown was followed by sawing a shrinkage specimen for Section II, 1 inch along the grain, 4 inches wide, and 1 inch in thickness.

Evaluation of Sample Material

As noted earlier, this report is on work that is now underway. All sample material has been collected and prepared. Determinations on the material are now being made to establish whether differences exist, and if so, how they relate to one another.

Section I — Color, Extractives, and Specific Gravity Determinations

Color evaluation. — The evaluation of color is especially important, for aesthetic reasons, in black walnut and some other hardwood species. Basic colors have generally, in the past, been described by qualitative terms such as dark brown, chocolate brown, etc. However, work done by Schwalbe and Ender (1934), Kollman (1939), Sandermann and Luthgens (1953), and many others has given us the opportunity to evaluate color quantitatively. Using the techniques described by Sullivan (1967a, b) the reflectance of each ¾-by 1- by

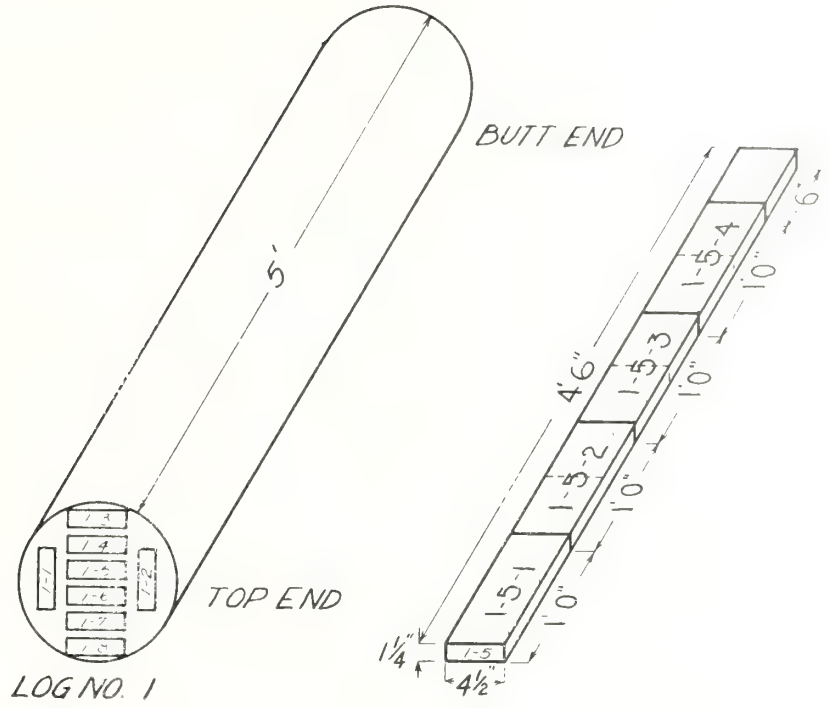

FIGURE 2. — Location of and numbering sequence for 1-foot samples in the boards.

3/16-inch piece (two per board) are being measured with a Beckman Model B spectrophotometer equipped with a reflectance apparatus. Each reflectance value is being measured as a percent of the reflectance of a standard surface, reflectance values being recorded at 10-millimicron intervals from 400 to 700 millimicrons (visible light region of the color spectrum).

These reflectance values are then utilized to derive the color's descriptive variables, i.e., dominant wavelength (millimicrons), saturation (percent of unity), and luminance (percent of unity).

Extractives and specific gravity. — After reflectance values are obtained on each ¾- by 1- by 3/16-inch piece, the material is ovendried and weighed. The samples are than placed in a Lloyd extractor for 3 weeks with alcohol-benzene as the solvent. After extraction, the water-saturated weight is determined and the samples ovendried and reweighed. Specific gravity on an extracted and unextracted basis is being calculated by the maximum moisture method as described by Smith (1955).

Percentage of total extractives is expressed on weight per weight, and on a weight per volume basis.

Section II — Wood Anatomy and Shrinkage Determination

Wood anatomy. — The material for study consists of 512 specimens, each 1 by ¾ by 3/16 inch. These are end matched to the color specimens and are obtained as described in Section I. The specimens are being airdried and then water saturated when measurements are to be made.

A transverse face of each specimen is being surfaced with a sliding microtome and, using a Zeiss integrating eyepiece and a 10X objective, the following are being determined:

1. Number of vessels per unit area.
2. Percent area occupied by vessel lumens.
3. Number of fibers per unit length in both the tangential and radial directions.

Using the formula for a rectangular cell model, the average cell wall thickness is being calculated according to Smith (1965), and from this, the average cell lumen diameter will be calculated.

Shrinkage and specific gravity. — The material for the study of shrinkage consists of 256 specimens, 4 by 1 by 1 inch. These are being obtained as described in Section I and as shown in figure 3.

Volumetric shrinkage and specific gravity are being determined on each specimen at 12-percent moisture content and again in the ovendry condition according to ASTM Standard D143-52. Volumetric shrinkage is being expressed as a percent of the green volume. Specific gravity is being expressed on the green volume-ovendry weight basis.

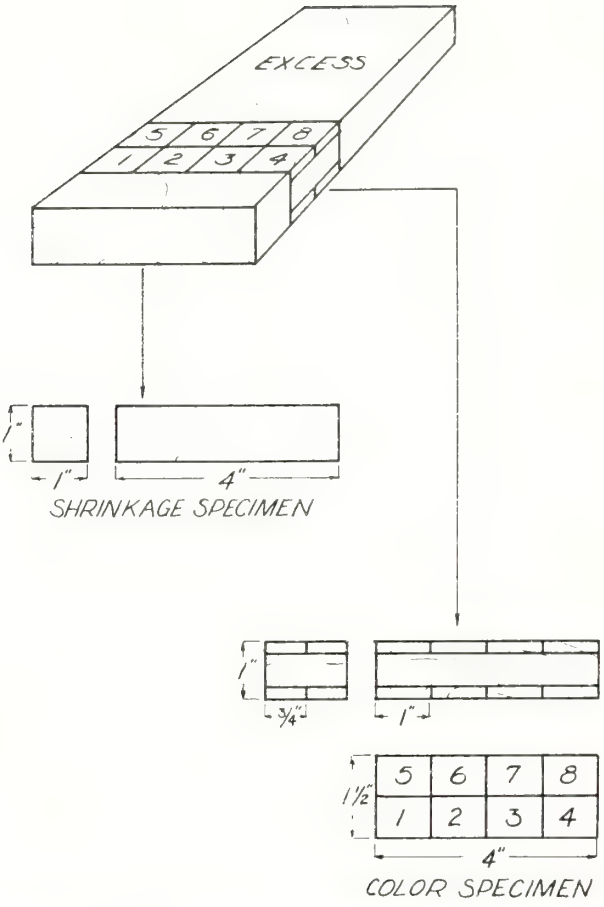

FIGURE 3. — Location of and numbering sequence showing shrinkage and color specimens.

Section III — Machining Characteristics and Mechanical Properties

Planing tests. — All of the 12-inch sample pieces are being dried to an equilibrium moisture content of 12 percent.

The samples are being planed to ⅛ inch on each face at a feed rate of 16 knife cuts per inch, after which all are examined for defects and smoothness.

Hardness and shaping tests. — One 12-inch board sample (adjacent to the 6-inch sample used in Sections I and II) was already selected for the hardness and shaping tests. One of the three remaining board samples is being randomly chosen for these same tests. The remaining two samples are used for the toughness and turning tests.

The hardness tests consist of three indentations of a ball 0.444 inch in diameter on each tangential face of the board; these are performed according to standard procedure (Amer. Soc. for Testing Materials, no date) by measuring the load to embed a 0.444-inch ball to one-half its diameter.

Following the hardness tests, the same pieces are used for the standard shaping tests (Davis 1962).

Toughness and turning tests. — The toughness and turning tests are made on ¾- by ¾- by 11-inch pieces cut from the remaining two 12-inch pieces. Every effort is being made to cut the toughness specimens with a tangential face and with minimum sloping grain. This may necessitate cutting the specimen diagonally from the ¾- by 4- by 12-inch sample. The turning specimens are cut adjacent to the toughness specimens, one from each of the two selected 12-inch pieces, and are ¾ by ¾ by 5 inches in size.

Summary

This is a report, before completion, of a program that the Forest Products Laboratory has embarked on. It is a concentrated program to find, if possible, one or more intrinsic wood quality criteria for black walnut and hopefully for other hardwood species as well. The program attempts to cover all of the main quality attributes desired by hardwood users. Further, it covers the possibility of finding relationships of these quality criteria to soil-site conditions.

The quality attribute most evident in the hardwoods is aesthetics, or color variation; this is being quantitatively evaluated with a spectrophotometer. Wood texture is being evaluated by anatomical characteristics; and shrinkage, specific gravity, machinability, and strength are being evaluated directly.

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STEM ANATOMY VARIATION IN COTTONWOOD GROWING UNDER NUTRIENT-DEFICIENT CONDITIONS

A. N. Foulger and J. Hacskaylo[1]

Investigations of mineral nutrient-tree growth relationships have dealt mainly with associations involving foliage composition, root formation, or volume production of wood. Few studies have been concerned with changes in wood anatomy associated with element deficiency. In 1949 Davis reported that calcium deficiency was accompanied by a reduction of primary tissue and an increase in secondary tissue in loblolly pine (*Pinus taeda* L.) stems. Murphey *et al.* (1962) found that nutrient defiencies affected the percentage of phloem formed and reduced both vessel diameter and the number of rays in sweetgum (*Liquidambar styraciflua* L.) seedlings. There was no apparent change in fibril angle.

The present study was a preliminary investigation into the degree of association between single mineral element deficiencies and anatomic characteristics in the stem of eastern cottonwood (*Populus deltoides* Bartr.) cuttings. All of the observations were made on first-year wood cuttings after 65 days of treatment. These data may, or may not, be applicable to mature plantation-grown trees. The hazards of extrapolating from data concerning rooted cuttings to considerably older stems are self-evident.

Material and Methods

First-year cuttings from a single eastern cottonwood, Wisconsin Clone No. 5, were rooted in quartz sand flats. When they were approximately 10 cm tall, they were planted in polyethylene-lined, 3-gal. crocks filled with HCl-washed silica quartz. Ten nutrient solutions, namely complete (table 1), -boron, -copper, -iron, -magnesium, -manganese, -nitrogen, -phosphrous, -potassium, and -suphur, were supplied to separate, continuously aerated crocks. Nutrient solutions were made from A.C.S. chemicals, with pure iron wire as a source of iron according to a modified Jacobson's method, and deionized water. If a compound supplied two elements to a solution, a sodium or chloride salt of the element not to be omitted was substituted. The pH of the solution was adjusted initially to 5.4 with 0.1 percent NaOH. The water level in the crocks was kept constant throughout the study, while pH was adjusted and nutrient solution changed every 2 weeks. Each treatment was randomly assigned to two trees in separate crocks. The plants were harvested after 65 days' treatment, height and stem diameters recorded on each, and the stems fixed in FAA.

Samples were taken from each stem at one-quarter, one-half, and three-quarters of the distance from the root collar to the stem apex. On a transverse section of the stem at each height, bark width, pith diameter, number and radial diameters of both vessels and fibers were recorded along 12 radii.

Macerations were prepared from stem portions immediately above each transverse section, allowing measurement of 50 fiber lengths and 30 vessel lengths and widths at each height in the stem.

Both the transverse section and maceration data were examined, using analysis of variance. Dunnett's procedure was employed to compare each treatment with the control, using a one-tailed test.

Results

Stem Height

The average stem heights after 65 days' treatment ranged from 138.5 cm for the complete to 38.5 cm for the S-deficient treatment as shown below.

Treatment	*Mean height (cm)*
Complete	138.5
-Boron	43.5*
-Copper	104.6

[1] *Respectively, Assistant Professor and Professor (now deceased) of Forestry at Ohio Agriculture Research and Development Center, Wooster, Ohio. The senior author is now Research Technologist, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture.* *The authors wish to recognize the assistance rendered by Misses G. Kirchhofer and B. March, who made the observations, and by Dr. C. R. Weaver, Statistics Laboratory, The Ohio Agricultural Research and Development Center. The work was supported in large measure by a grant from Champion Papers Incorporated, Knightsbridge, Hamilton, Ohio.*

Table 1. — Compounds in the complete nutrient solution

Compound		Total parts per million of element
$Ca(NO_3)_2 \cdot 4H_2O$	Calcium (Ca)	120.21
	Nitrogen (N)	112.00
KNO_3	Potassium (K)	156.36
KH_2PO_4	Phosphorus (P)	62.05
$MgSO_4 \cdot 7H_2O$	Magnesium (Mg)	48.65
	Sulfur (S)	64.12
Fe - EDTA	Iron (I)	5.00
H_3BO_3	Boron (B)	0.40
$MnCl_2 \cdot 4H_2O$	Manganese (Mn)	0.40
$ZnCl_2$	Zinc (Zn)	0.05
$CuCl_2 \cdot 2H_2O$	Copper (Cu)	0.02
MoO_3	Molybdenum (Mo)	0.03

Treatment	*Mean height (cm)*
-Iron	108.4
-Potassium	98.9
-Magnesium	123.1
-Manganese	124.1
-Nitrogen	49.7*
-Phosphorus	102.9
-Sulfur	38.5*

Deficiencies of B, N, and S resulted in height reductions which were significant at the 5-percent level (indicated by an asterisk in the tabulation).

Fibers

A decrease in fiber length, significant at the 5-percent level, was found at two or more levels in the stem with deficiences of B, K, N, and S (fig. 1). Only in the top specimens did lack of Cu, Fe, Mg, Mn, and P cause significant reductions in fiber length. Both -Cu and -Mn treatments resulted in slight increases in fiber length at the lowest level in the stem.

In addition to a reduction in fiber length, deficiences of K, N, and S were associated with a significant reduction in fiber width at all levels in the stem (fig. 1). Mean fiber width was reduced in the top specimen from the Mg treatment, but no significant decrease or increase in fiber width was associated with a lack of the other elements.

The number of fibers formed was significantly reduced at all three stem levels in the absence of N and S while -B, -K, -Mg, -Mn, and -P were associated with significant reductions at the lower two levels (fig. 2).

Ring width due to fibers, shown in figure 3, has a pattern similar to figure 2. Deficiencies of Mg, N, and S caused a significant reduction at all three levels in the stem, while the absence of B, K, Mn, or P was accompanied by a reduction at the middle and bottom levels. However, a lack of Cu and Fe had no apparent effect on the amount of wood made up of fibers.

Vessels

No significant differences in vessel length were found with any of the treatments (fig. 4). Radial

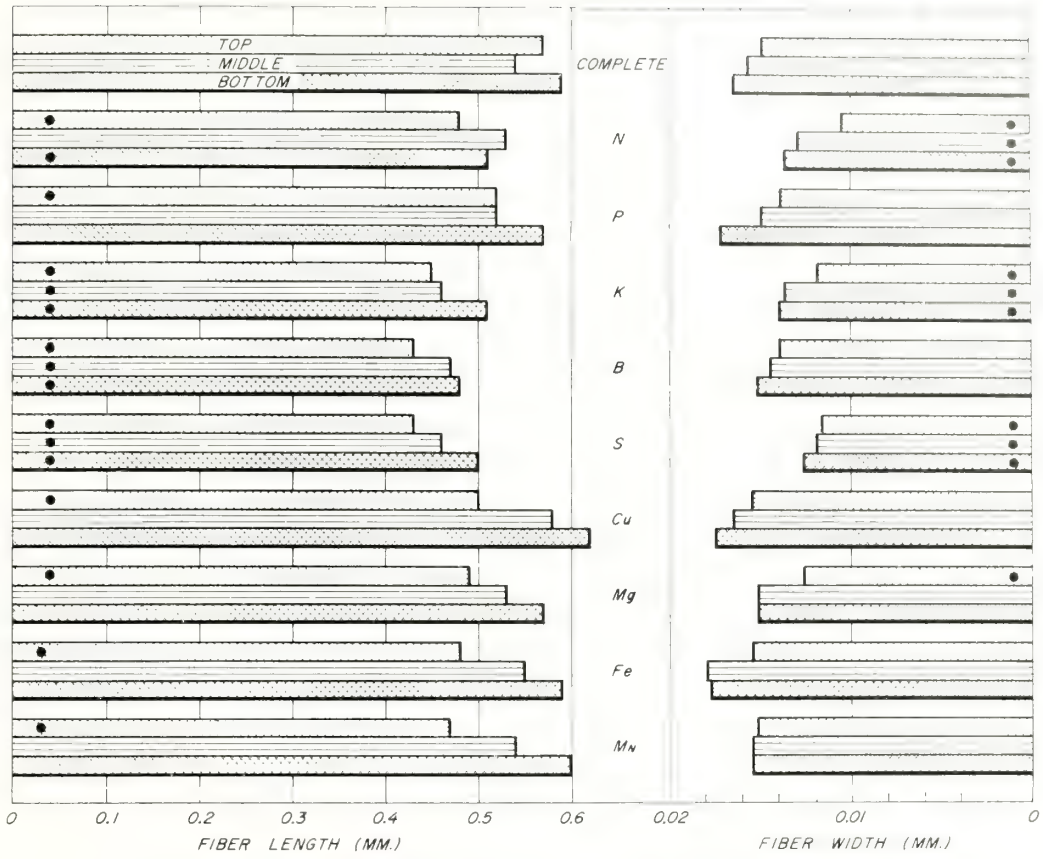

FIGURE 1. — Mean fiber length and width at each level in the stem is shown with the particular element which is absent. In this and following figures a dot indicates a value significantly different (0.05) from the complete treatment value at the corresponding stem position.

vessel width, as measured on the cross sections, showed a significant decrease at all levels in the stem in the absence of N, and S, and in the upper two levels when B was absent. The other treatments showed no effect on vessel width. Vessel widths were slightly larger for the macerated material since the vessel segments had been flattened under the cover slip. These measurements indicated that -B, -N, and -S all were associated with reduced vessel width at all three levels in the stem. A deficiency of K caused a significant decrease in the top and middle of the stems. With the exception of -Mg, where vessel width increased slightly in the top of the stem, -Cu, -Fe, -Mn, and -P reduced vessel segment width significantly in the lower portion of the stem, the latter two also causing a reduction at the middle level.

Only -S was associated with a reduced number of vessels at all three levels in the stem (fig. 2), but all other element deficiencies caused a reduction in the middle and bottom of the stem.

Bark

The bark of young cottonwood has pronounced vertical ridges, which resulted in considerable variation in bark width for the same section. Mean bark thickness was reduced significantly at the top of the stem in the absence of Cu, Fe, K, Mg, Mn, N, and P, and at the bottom with a lack of K, Mg, Mn, N, or S (fig. 5). There was no significant reduction in bark width with the -B treatment.

Pith

Pith diameter was significantly less than the control at all three heights in the stem with B, Cu, K, Mn, N, P, and S deficiences (fig. 5). In the absence of Fe and Mg, pith diameter was reduced in the top and middle of the stem.

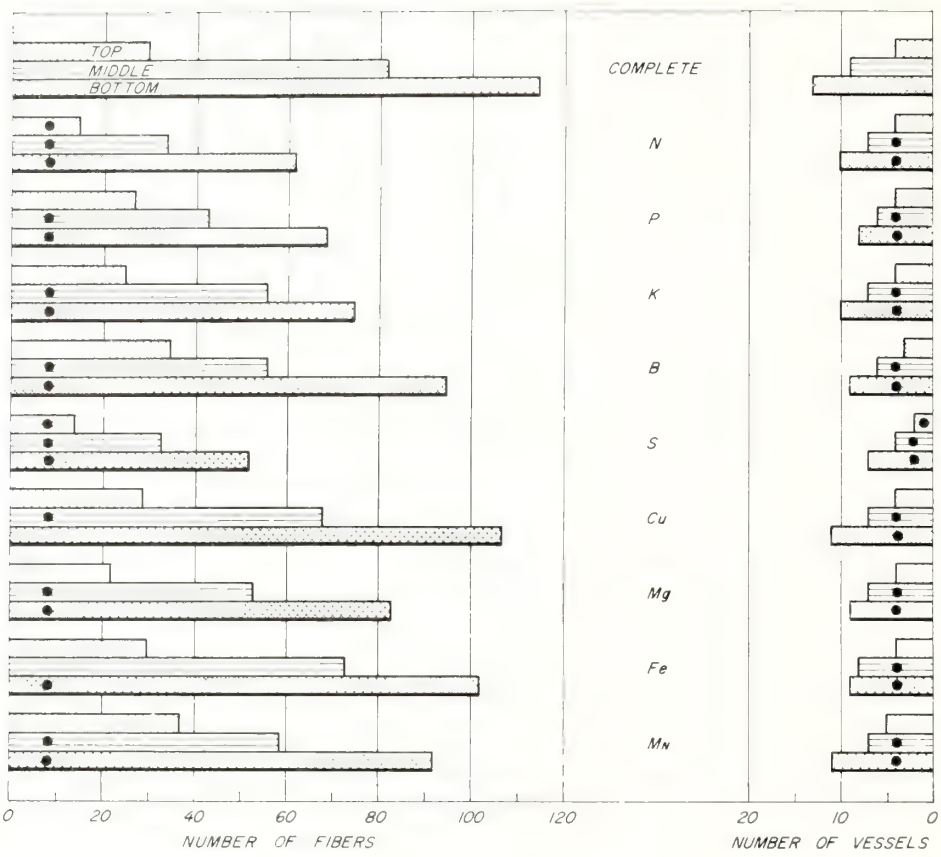

FIGURE 2. — Mean number of fibers and vessels per radius at each level in the stem is shown with the particular element which is absent.

Relationship Between Anatomic Characteristics

Data from all 10 treatments were grouped together by in-stem position (i.e., top, middle, bottom), and analysis of variance was used to determine the amount of correlation between certain of the anatomic characteristics measured. Those pairs of characteristics with a significant correlation are shown in table 2. Both fiber width and vessel width, as measured on the cross sections, showed a significant association with ring width at all three levels in the stem, but the correlation between ring width and macerated vessel width was significant only in the two lower positions. Ring width and fiber length were correlated significantly only at the bottom of the stems, while fiber length varied linearly with change in fiber width in the middle and bottom of the stems. Only vessel segment length at mid-height in the stem showed a significant relationship, at P equals 0.95, with vessel width and with ring width.

Discussion

The sampling method used in the study may be questioned in that comparison is made between points nominally similar in the stem, but which practically may be at quite different distances from the stem apex. From one standpoint, it might have been more desirable to compare points on the stem at a specific distance below the apex. However, the shortest specimen was 34.0 cm tall at the end of the study, and since the specimens were approximately 10 cm tall at the start, sampling would have been limited to the topmost 20 cm of each stem. Because an estimate of overall stem development was desired, it was decided that the sampling system used would give the most meaningful results for this particular study.

Of the various observations, possibly the most noteworthy is the thoroughly debilitating effect of N and S deficiences, which were associated with

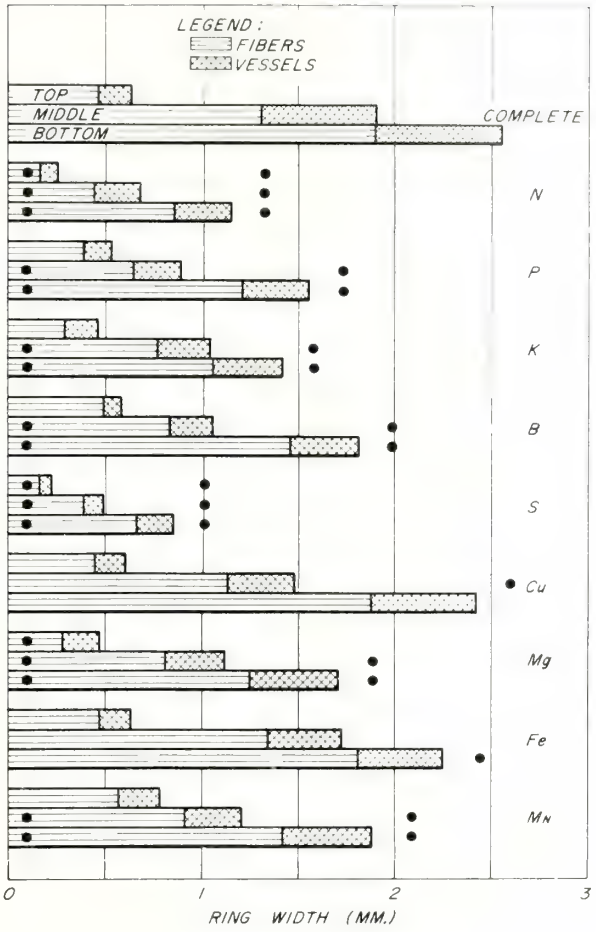

FIGURE 3. — Mean radial ring width due to fibers (lined) and to vessels (hatched). Together the two comprise total ring width at each level in the stem by treatment. Dots on the lined area indicate significant differences in width due to fibers, while dots to the right of the graphs show differences in total ring width.

significant reductions in fiber length and width, vessel width, ring width, bark width, and pith diameter. In addition, the lack of B, K, and, to a lesser extent, P resulted in marked reductions in size and number of fibers and vessels. Not only is there a reduction in the amount of wood formed, but there is a change in fiber and vessel anatomy. On calculating the ratio of vessel-formed wood to fiber-formed wood, the -N treatment showed an increase in the ratio of vessel wood to fiber wood. While these five elements, i.e., N, S, B, K, and P, have an overall effect on stem anatomy, each of the other treatments affected one or more of the facets studied. Significant reductions in both wood and bark width occurred with K, N, P, and S deficiencies while only wood formation was reduced in the absence of B.

Of these five elements, N, S, and probably K are directly involved in protein synthesis. N is essential to all amino acids, and is found in some vitamins. In addition, S is a constituent of the plant hormones biotin and thiamine, while a prolonged lack of K results in a reduction of carbohydrates. The role of B in plants is not known precisely, but this element appears to be necessary in carbohydrate transport, while a deficiency of it reduces the rate of protein synthesis. The nucleic acids contain P, and a lack of P also limits protein production since it plays an important role in energy transfer.

The primary function of the study was to determine which elements were associated with ma-

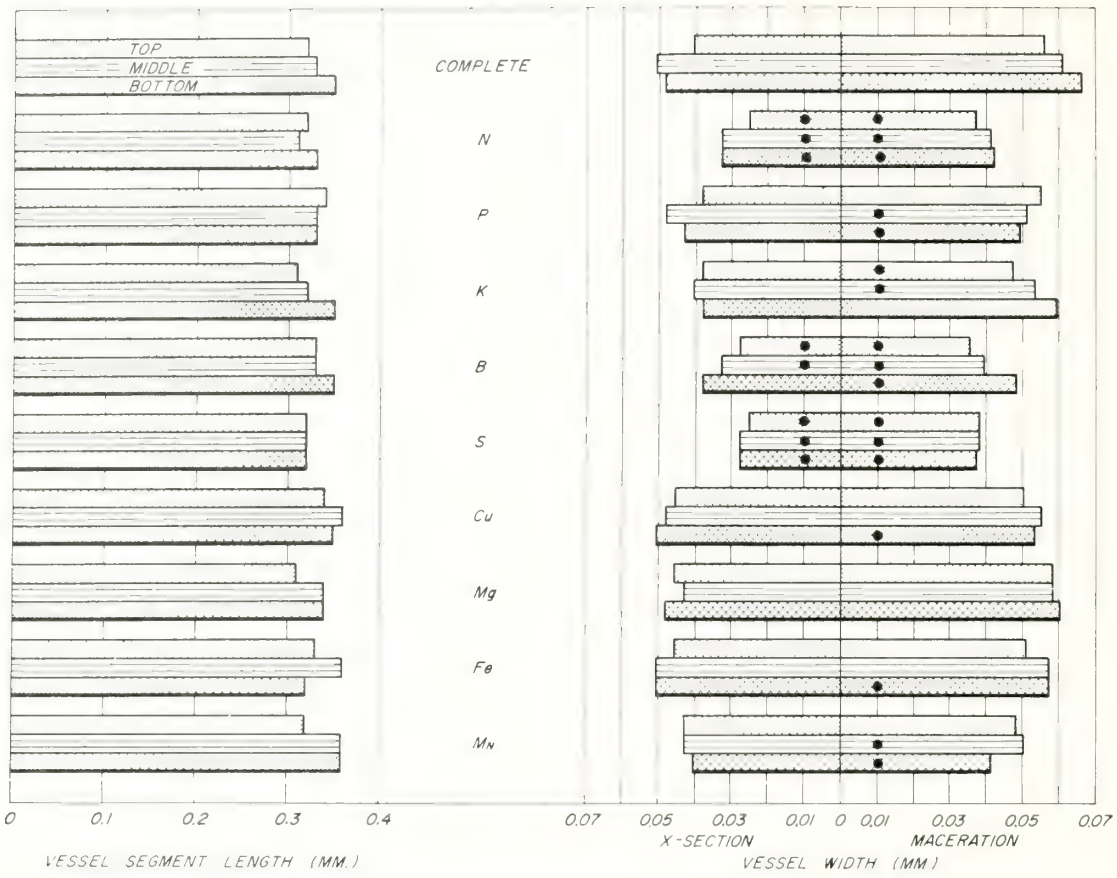

FIGURE 4. — Mean vessel segment length and width at each level in the stem is shown with the particular element which is absent. Two vessel widths are shown; those on the left are cross-section measurements while those on the right are from macerated material.

jor changes in stem anatomy, and with those anatomical aspects of economic importance to the pulp and paper industry. With this in mind, it seems that N, S, B, or K deficiency would cause most embarrassment to the woodland manager in reduced volume production, and, possibly, to the mill production engineer due to altered wood anatomy. Other elements do affect various facets of growth, but absence of the four mentioned above was accompanied by significant departures from "normal" in most of the anatomic characteristics examined.

The effects of the several element deficiencies on foliage appearance and the chemical composition of the roots, stem, and leaves of cottonwood seedlings have been reported elsewhere by Hacskaylo (1966). While the anatomic changes associated with particular element deficiencies were less marked than those of leaf form and color, the variation from "normal" was significant in several instances. It is doubtful if these data can be extrapolated to apply to stands 10 years of age or older. A further complication lies in the fact that nutrient-deficient soils frequently, though not invariably, are lacking in more than one element, and are most unlikely to have one element completely absent.

The data presented herein are applicable to young cottonwood, possibly up to 5 years of age, with some degree of confidence. Additional work is required to determine the effects of varying two or more elements simultaneously, and the effect of nutrient deficiencies on the stem anatomy of older trees.

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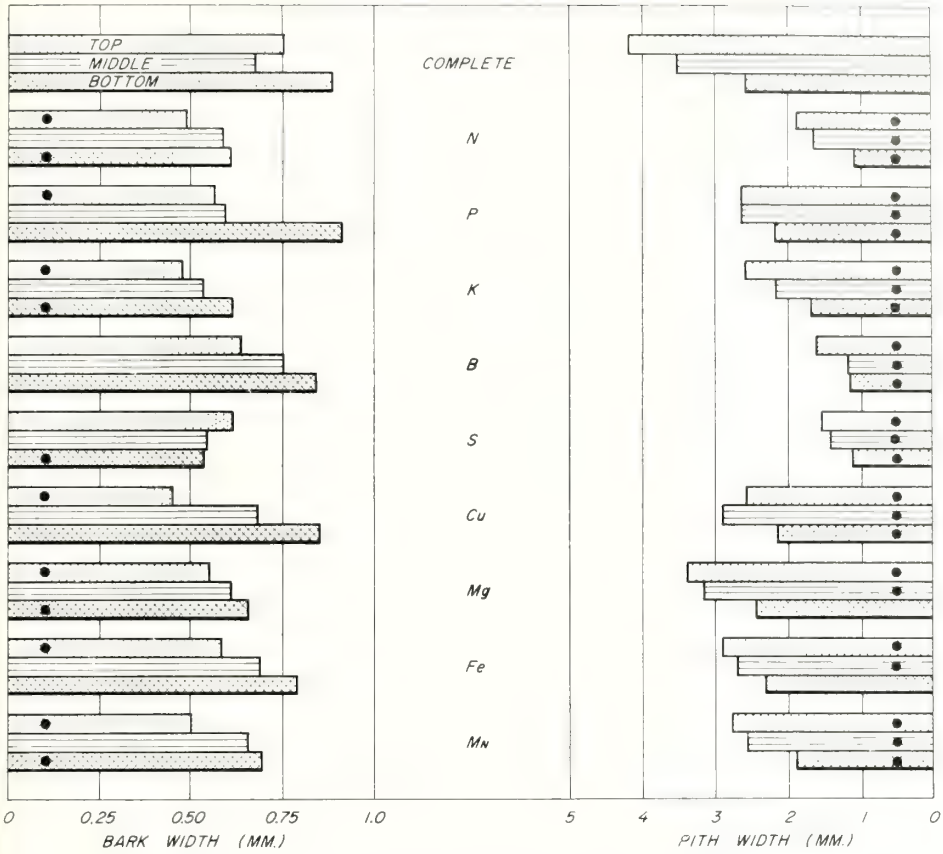

FIGURE 5. — Mean bark width and pith diameter at each level in the stem is shown with the particular element which is absent.

Table 2. — Correlation coefficient, mean and standard error of estimate for pairs of anatomic features by stem position for all specimens taken together

X	Y	Stem position 1/	Correlation coefficient, all positive	Mean Y (mm.)	Standard error of estimate of Y
Fiber length	Fiber width	T	0.511	0.014	0.001
		M	.681*	.015	.001
		B	.716**	.016	.001
Ring width	Fiber width	T	.877**	.014	.001
		M	.894**	.015	.001
		B	.778**	.016	.001
Ring width	Fiber length	T	.364	.487	.039
		M	.562	.519	.032
		B	.738*	.553	.029
Ring width	Vessel width (cross-section)	T	.703*	.038	.006
		M	.854**	.042	.004
		B	.883**	.043	.004
Ring width	Vessel width (maceration)	T	.525	.049	.007
		M	.771**	.051	.005
		B	.668*	.052	.007

1/ T = top; M = middle; B = bottom.
* Significant at the 5-percent level.
** Significant at the 1-percent level.

THE GROWTH AND ANATOMICAL FEATURES OF NUTRIENT-DEFICIENT SEEDLINGS

Fred M. Lamb and Wayne K. Murphey[1]

As the tree improvement and genetic programs supply better planting stock, a more suitable environment must be provided if their full potential is to be realized. This will require much more information than we now have on how nutrient deficiencies affect the growth and anatomy of forest trees. The importance of anatomical studies has been shown by Church (1949) and Harper (1913). They found that one of the first effects of defoliation is a marked reduction in latewood formation. Furthermore, the assumption that anatomical features exert an influence on the physical and mechanical properties of wood through alterations in specific gravity is generally accepted.

This paper reports the effects of various nutrient deficiencies on the growth and anatomical properties of silver maple (*Acer saccharinum* L.) seedlings. The nutrient elements chosen for investigation were calcium (Ca), boron (B), magnesium (Mg), and phosphorus (P). These were selected primarily because of their physiological functions: Calcium and boron are involved in the meristematic activities. Magnesium is a prime constituent of the chlorophyll molecule, and phosphorus is engaged in energy transfer and is a structural component of deoxyribose nucleic acid and ribonucleic acid.

Total height, diameter, and dry weight of the stem were measured to study growth effects. Maximum root length was also measured as an indication of the absorbing capacity of the seedlings. The anatomical features investigated were the vessels representing the conductive cells, the fibers representing the support cells, and the width of secondary xylem.

Methods

To limit genetic variation, seeds of equal size and weight were obtained from a single silver maple tree, and then only those seeds that germinated within a middle 24-hour period were used in the study.

After the seeds had germinated in a tray lined with moist filter paper, the selected materials were transferred to polyethylene-lined pots containing sterilized vermiculite and were supplied for 2 weeks with deionized water only. Then 25 seedlings were placed in a growth chamber, and each group of five seedlings received one of five nutrient solutions. One, a modified Hoagland's solution (Davis 1949, Hoagland 1948, and Went 1957) containing all nutrients, was given to the controls. The other four solutions were prepared in a similar manner except that each had one of the four study elements withheld. In the growth chamber, day length was maintained at 15 hours, temperature was held at 27° C, and the solutions were constantly aerated.

After 12 weeks in the chamber, the seedlings were observed for foliar symptoms denoting the various deficiencies, and growth data were recorded. To study the anatomical features, a 1-inch-long section was cut from each stem directly above the root collar, embedded in celloidin, and sectioned on a sliding microtome. The 10-micron-thick sections were then stained with Safranin Y and Delafield's Haematoxylin and mounted with a synthetic resin. The embedding and stain procedures used are outlined in Sass (1958).

Significance was tested by means of the analysis of variance, using a completely random design. Tukey's HSD (Tukey 1949) was used as a mean separation test to determine which treatments were significantly different .

Foliar Symptoms

Calcium deficiency was characterized by necrotic marginal areas on the older leaves. The young leaves were pale green and distorted, and had curled margins.

The foliage of the magnesium-deficient plants exhibited interveinal necrosis and marginal chlorosis. The plants themselves were characterized by rosetting.

Areas of chlorosis throughout the leaf surface were noted on the boron-deficient plants. The leaves had a silvery appearance and a thickened texture.

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In the early stages of phosphorus deficiency, the older leaves were dark green while the younger leaves were a somewhat lighter shade. As the deficiency progressed, the older leaves became necrotic and the younger ones turned dark green with light green veins.

External Features

The data show that the phosphorus-, magnesium-, and calcium-deficient seedlings were all significantly lower in stem dry weight than the controls (table 1). A significant reduction in maximum stem height occurred in the calcium-deficient seedlings, while both calcium- and boron-deficient series had significantly reduced root lengths. Only the magnesium-deficient series differed significantly from the control in stem diameter.

Anatomical Features

All four nutrient-deficient series had significantly larger fiber diameters than the controls (table 2). All the nutrient-deficient series except magnesium had significantly larger vessel diameters with a corresponding significant reduction in vessel distribution. For the width of secondary xylem, only the magnesium- and calcium-deficient series differed significantly from the controls.

Discussion

The foliar symptoms found in this study serve as evidence that the seedlings were in fact subjected to the various nutrient deficiences. For the most part the symptoms that occurred coincide with the findings of other workers (Childers 1954, Hacskaylo 1960, Hobbs 1944, Mitchell 1939, and Pessin 1937).

Nutrient deficiences primarily cause disruptions of physiological processes which, in turn, may alter growth and anatomical features. Therefore, the results obtained in this study must be considered as secondary effects. We can only speculate as to what the biochemical effects are since little information of this sort is available on forest trees. There is also a question as to how well the effects of nutrient deficiencies on seedlings can be considered as representing those that might occur on larger trees, since juvenile wood is expected to differ from mature wood. Nevertheless, it has been established that early anatomical differences can be used to forecast future trends. With these thoughts in mind, let us consider the effects of each nutrient deficiency in turn.

The minor element, boron, is necessary in only minute quantities, but it is essential for vigorous growth. It affects cell division, nitrogen metabolism, carbohydrate metabolism, active salt absorption, hormone movement and action, and metabolism of pectic substances. It is a constituent of

Table 1. — Seedling means arranged in order of magnitude by nutrient-deficiency treatment[1]

Dry weight of stem		Height		Root length		Stem diameter	
Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean
	(Grams)		(Cm)		(Cm)		(Mm)
-B	0.481	-B	27.7	-P	36.0	Control	1.55
Control	.455	Control	27.5	Control	35.8	-B	1.50
-P	.296	-P	21.5	-Mg	34.0	-P	1.40
-Mg	.146	-Mg	20.9	-B	26.4	-Ca	1.29
-Ca	.074	-Ca	14.9	-Ca	10.0	-Mg	1.18

[1/] Based on five trees for each treatment. Any two means not scored by the same line are significantly different.

Table 2. — Seedling means of various anatomical features arranged in order of magnitude by nutrient-deficiency treatment[1]

Fiber diameter		Vessel diameter		Vessel distribution[2]		Width of secondary xylem	
Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean
	(Microns)		(Microns)		(No.)		(Microns)
-P	16.0	-B	28.8	Control	13	-B	294
-Ca	15.1	-Ca	27.1	-Mg	12	Control	280
-B	14.9	-P	27.1	-P	9	-P	246
-Mg	13.3	-Mg	25.7	-B	9	-Mg	162
Control	10.8	Control	23.8	-Ca	6	-Ca	151

[1] Based on five trees per treatment. Any two means not scored by the same line are significantly different.

[2] Per 25,000 square microns.

membranes, serves to increase the solubility of calcium, and acts in precipitating excess cations. Boron is said to be necessary in the maintenance of conducting tissues. In this study, neither the height, diameter, nor dry weight of stem of the boron-deficient seedlings differed from those of the controls; but the root length did. The roots of the boron-deficient seedlings were more or less stunted. This corresponds to the results of Sommer and Sorokin (1928). The reduction in root growth may seriously affect the development of the seedlings by impairing the uptake of water and the accumulation of salts.

With regard to anatomical features, the boron-deficient seedlings had larger fibers and vessels and consequently fewer vessels per unit area than the controls. These changes may be the result of alterations in physiological processes, such as cell division, caused by the lack of boron. Warington (1926), working on the anatomical effects of boron deficiency, found an abnormal enlargement of the cambial cells.

Calcium is a major element required in large quantities for plant growth. It affects the activities of certain enzymes but is especially important in combining with pectin to form calcium pectate, a constitutent of the intercellular substance. It reduces the toxic effects of magnesium, sodium, and potassium, and neutralizes certain organic acids. At the growing points, calcium has an enzymatic function. The reductions in growth obtained in this study for the calcium-deficient seedlings agree with the results of other workers investigating calcium deficiencies (Hobbs 1944, Mitchell 1939, Pessin 1937, and Wyatt 1961). The growth losses may well result from the lack of calcium (1) to stimulate enzymatic action and possibly (2) to reduce the toxic effect of certain salts and to neutralize certain organic acids.

The calcium-deficient seedlings also differed from the controls in all four anatomical features. These results correspond to those of Davis (1949) who found in calcium-deficient *Pinus taeda* a decrease in cell division accompanied by an increase in cell enlargement and cell differentiation in the secondary xylem. Venning (1953) found a reduction in cambial activity and amount of secondary xylem in calcium-deficient tomato (*Lycopersicon* spp.) plants. These alterations of the anatomical features may well reflect calcium's enzymatic role in the meristematic regions of the plants.

Magnesium is active in the enzymatic system and is a possible carrier of phosphorus. The reduced stem diameter and dry weight of stem exhibited by the magnesium-deficient seedlings is probably a secondary effect since one of the prime functions of magnesium is as the central component of the chlorophyll molecule. Therefore, a deficiency of this element would greatly reduce the rate of photosynthesis. Pessin (1937) and Wyatt (1961) also showed a reduction in growth due to magnesium deficiency.

As to the anatomical features, the reduction in secondary xylem is understandable as this is in accordance with the general reduction in growth previously noted. However, the enlargement of the fibers occurring without an accompanying

change in the size and distribution of vessels is not so easily understood. Possibly a deficiency of magnesium has a much greater effect on the support cells than on the conductive elements of the secondary xylem.

Phosphorus is necessary for photosynthesis, the synthesis of carbohydrates, and the transfer of energy within the plant. It is a structural component of nucleic acid, which includes RNA and DNA. The reduction in dry weight of the phosphorus-deficient seedlings occurred even though the stems were of approximately the same size as the controls. The phosphorus-deficient seedlings, however, had stems which were composed primarily of young succulent tissue with larger fiber and vessel diameters and correspondingly fewer vessels per unit area than in the controls. These anatomical alterations may well reflect the role of phosphorus in the organization of the cells and in the transfer of hereditary characteristics.

Conclusions

The results of this study indicate that nutrient deficiencies in forest trees may cause disruptions of certain physiological processes which, in turn, may result in reduction of growth and alteration of anatomical features.

Much work remains before the complete effects of nutrient deficiences on growth and anatomy of forest trees are fully understood. The interaction between nutrient elements is highly complex. Therefore, it is difficult to assign one particular anatomical or growth alteration to a deficiency of a single element. This information is vital, however, if the full potential of our tree improvement programs are to be realized outside the laboratory.

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CURRENT WORK IN ONTARIO ON COMPRESSION WOOD IN BLACK SPRUCE IN RELATION TO PULP YIELD AND QUALITY

J. L. Ladell, A. J. Carmichael, and G. H. S. Thomas[1]

In 1959 and 1960, during a series of symposia on wood quality organized jointly by the Ontario Department of Lands and Forests, the Faculty of Forestry of the University of Toronto, and the Ontario Research Foundation (ORF), it became clear that there was a serious lack of information regarding the structure and variability of the wood of the commercially important species of Ontario. Following these symposia a Wood Quality Unit was set up within the Department of Lands and Forests' Research Branch, and at about the same time the Department undertook to sponsor a wood quality research program to be carried out by the Department of Organic Chemistry of the ORF, which for many years had been doing contract research in the fields — among others — of lignin chemistry and the utilization of waste pulping liquor.

As the pulp and paper industry is basic to the economy of Ontario and as black spruce (*Picea mariana* (Mill.) B.S.P.) provides over 50 percent of the raw material used by that industry, it was decided to concentrate on this species. At present the major research effort is directed at attempting to relate specific paper properties to anatomical characters and these latter, in turn, to such factors as growth rate, age, and site. It is hoped that the results will be useful in the management of existing stands as well as furnish information that will assist in the selection of superior trees for breeding purposes.

A multi-unit micro pulp digester, based on a design found to be efficient by the Institute of Paper Chemistry, Appleton, Wis., has been built at the Foundation, while other facilities are currently being used to study problems ranging from the distribution of resins in black spruce in relation to deresination methods in pulp mills to the feasibility of exploiting the foliage of black spruce commercially.

Throughout this work the ORF has cooperated closely with the Wood Quality Unit of the Department of Lands and Forests' Research Branch. This unit has concerned itself with the investigation of field sampling problems and the difficulties of typifying whole tree characteristics from a limited number of increment cores. During these investigations it was observed that a large number of black spruce cores contained compression wood. Compression wood, found typically on the lower side of leaning trees and on the underside of branches, is composed of relatively weak, rounded, thick-walled cells rich in lignin — all factors likely to detract from the quality of pulp and paper. Although much information is available on some aspects of compression wood such as its microstructure and the factors that appear to cause its formation, its distribution within trees and stands and its effect on pulp and paper quality have not been investigated with any thoroughness. The distribution of compression wood in the southern pines has been studied, for example, by Zobel and Haught (1962) and by Einspahr *et al.* (1962), and in *Juniperus procera*, an African species, by Phillips (1940). More recently Low (1964) studied the distribution of compression wood in Scots pine grown in the United Kingdom. The effect of compression wood on the pulp and papermaking properties of loblolly pine (*Pinus taeda* L.) has been investigated by Pillow and his coworkers (1935, 1941), while a study on *Pinus radiata* was reported by Watson and Dadswell (1957).

Moore and Yorston (1945), in an early review of the effect of wood properties on the quality of pulp and paper, give values showing that the inclusion of compression wood in balsam fir (*Abies balsamea* (L.) Mill.) sulfite pulp results in decreased yields and lower burst strength. There are other scattered references to the general effect of compression wood on pulp quality in the northern spruces, as, for example, by Green and Yorston (1939) in a discussion of "acid susceptible" wood. But as far as the writers are aware, compression wood in black spruce has been the subject of only one investigation — and that a minor one — dealing with mechanical pulp (Pillow *et al.* 1959). In view of the frequency, mentioned above, with which compression wood was observed in black spruce increment cores, a detailed study of the distribution of this abnormality in relation to pulp and paper quality appeared to be of basic importance to the research program.

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Amount and Distribution of Compression Wood

In a pilot study, estimates of compression wood were made on discs from the 10- and 75-percent height levels of 20 mature trees on a good site in Parnell Township, Ontario, using an adaptation of the point sampling technique employed, for example, by Ladell (1959), Myint Aung (1962), and Tsoumis (1964) for estimating the ratio of cell wall to lumen, or the frequency of different cell types on microscope sections. A transparent sheet of plastic with a known number of randomly placed dots was placed over discs, smoothed and wetted to accentuate the bands of compression wood, and counts were made of the number of points falling on them. With allowance made for points not falling on the disc (the count field was square), the amount of compression wood relative to the whole could be determined. Trials showed that six counts using approximately 100 points, repeated with the count field randomly placed each time, gave good reproducibility. Indirect evidence of the reliability of the method was subsequently obtained from pulping trials, as will be seen.

The results of this investigation showed that at the 10-percent height level, compression wood content in the 20 trees averaged 5.8 percent, with individual trees ranging from 3.1 to 11.3 percent. Corresponding values at the 75-percent height level were 0.0 to 5.1 percent, with a mean of 2.3 percent. No correlation was found between levels ($r=-0.075$ not significant).

The second and much more detailed investigation involved 11 mature trees from a good lowland site in Challies Township, Ontario. These trees were part of a sample collected earlier in connection with a study of specific gravity distribution. The sampling plan called for random selection with the rejection of trees with perceptible lean or crook, but in fact no such trees fell within the sample although the stand contained such trees. Each tree had been reduced in its entirety to 1-inch discs up to the 90-percent height level. Estimates of compression wood were now made on every 15th disc, using the method described above with the refinement that a series of circular count fields of varying diameters was employed.

Estimates on all discs within each 10-percent height increment were averaged to give nine mean values for each tree centered on the 5-, 15-, 25-percent, etc., up to the 85-percent height level. Generally, five discs contributed to each value, the exact number depending on the height of the individual trees, which varied from 50 to 63 feet.

Table 1 lists the average compression wood contents for each tree. The values in the lefthand column are simple averages; those in the right were obtained by weighting the values for the different levels by wood volume. Simple tree averages ranged from 6.4 to 27.1 percent, with an overall mean of 14.7 percent. The weighted averages ranged from 5.3 to 26.1 percent, with an overall mean of 13.9 percent and a standard deviation of 1.83 percent. As leaning trees were not represented in the sample, the value of 13.9 percent can be considered as an underestimate of the average compression wood content of the stand.

Unweighted compression wood mean values from all trees by tree height tended generally to be high in the crown and at the base of trees (fig. 1). Patterns of variation in individual trees varied widely, however. In four trees — numbers 8, 11, 17, and 20 — the peaks at base and crown were very marked, whereas in another four trees — numbers 7, 14, 15, and 16 — compression wood content tended to increase more or less steadily with height within the tree. In trees numbered 13 and 21, compression wood tended to decrease with height. In spite of the diversity of trends with respect to height displayed by individual trees, compression wood content within trees was remarkably consistent. Except for the 85-percent level, the relationship between compression wood percent at each level and weighted tree means was very close, with correlation coefficients ranging from $+0.788^{**}$ to $+0.961^{***}$ (fig. 2). For the 85-

Table 1. — Average compression wood content in 11 black spruce trees

Tree number	Simple average (percent)	Weighted average (percent)	Tree number	Simple average (percent)	Weighted average (percent)
7	6.4	5.3	16	14.6	12.0
8	10.3	10.8	17	17.3	17.3
11	17.5	16.9	18	13.4	11.2
13	8.3	9.3	20	19.3	18.4
14	27.1	26.1	21	18.2	18.6
15	9.6	7.4	Mean	14.7	13.9

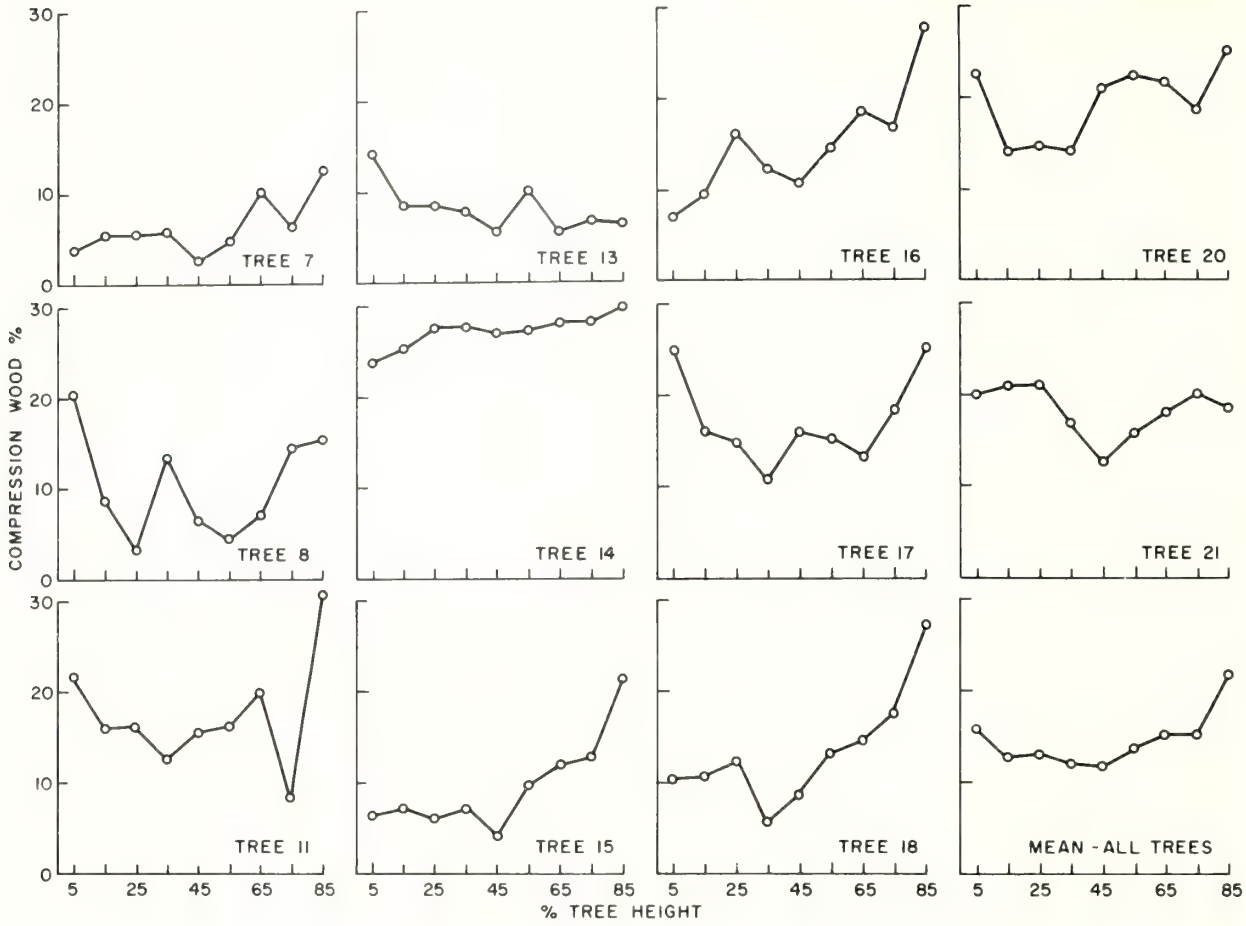

FIGURE 1. — Variation of compression wood content with height in each of 11 black spruce trees and in all trees combined.

percent level r was calculated at 0.597 (not sig.). If the results of the second, more intensive investigation can be confirmed it would appear that, to predict total compression wood from increment cores, the cores should be taken somewhat above breast height, perhaps at the 15-percent level where r was found to be +0.959. Studies of the predictive capability of increment core samples are at present underway, as are other confirmatory investigations.

Pulping Trials

The primary objective of the first pulping trial was to obtain indirect confirmation of the efficiency of the method used to estimate compression wood. As compression wood is abnormally high in lignin, and as high lignin content tends to reduce the yield of pulp, given equivalent pulping conditions, then a negative correlation between pulp yield and compression wood content might be expected — if the latter had been estimated correctly.

Accordingly, from the 11 trees mentioned above, 68 samples of known compression wood content were chipped and cooked for 3 hours using sodium bisulphite. Weight of chemical was 20 percent that of the wood. Liquor to wood ratio was 5 to 1, so that actual concentration of chemical was 4 percent. Percent screened pulp yields were determined for each of the 68 pulps prepared; the relations between percent compression wood and pulp yield were then analyzed statistically, with Kappa number taken to be a covariable;[2] and the coefficient of correlation between yield and compression wood content was calculated. This was —0.745 and significant at over the 0.1-percent level.

[2] *Kappa number, as a measure of residual lignin, indicates the degree to which a pulp has been cooked and is commonly used as a basis for the comparison of pulps.*

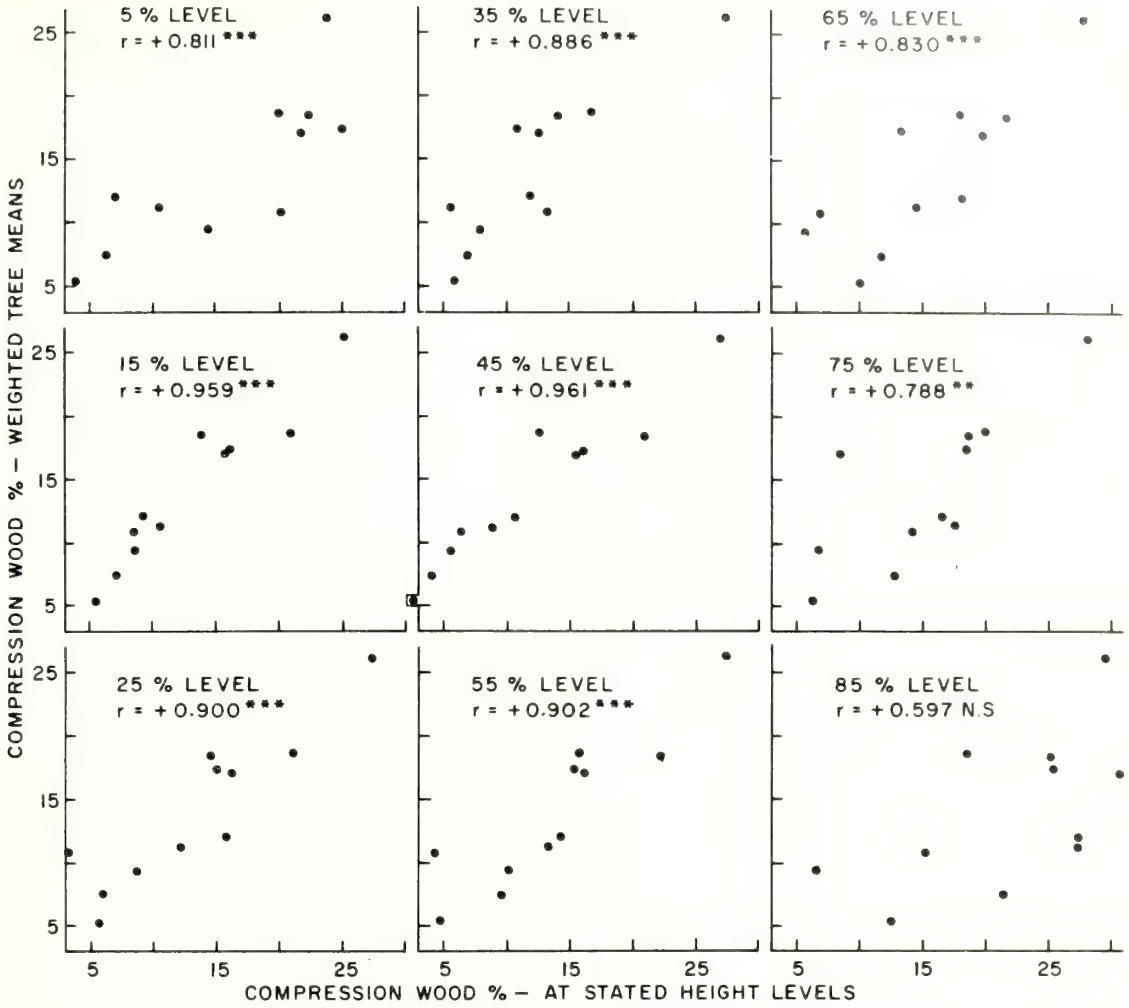

FIGURE 2. — Relation in 11 black spruce trees between the mean compression wood content of entire trees and the compression wood content at nine predetermined height levels.

The regression of yield on compression wood percent was calculated as $Y=53.05-0.2910X$, a linear relation being assumed. The regression was highly significant ($F=82.18^{***}$), with compression wood accounting for 55.5 percent of the variation in yield. An estimate of the effect of compression wood on yield from pulps cooked to known lignin content was obtained by calculating a further regression, with the Kappa number of the pulps as a second independent variable. The regression was $Y=44.99-0.25X_1 + 0.14X_2$ ($F=91.17^{***}$) where X_1 = percent compression wood and X_2 = Kappa number (fig. 3). Each variable was highly significant when the effect of the other was removed. F was 97.23^{***} for compression wood and 45.16^{***} for Kappa number.

It was felt that these results amply proved the accuracy of the point sampling system of estimating compression wood. The results also suggest that compression wood content might prove to be a useful indicator of yield. This possibility is now being examined in the light of specific gravity differences in the same set of samples.

Characteristics of Black Spruce Compression Wood and Effects on Paper Strength

Three mature trees with pronounced lean were selected from a stand in Fournier Township, and a 4-foot bolt centered on the breast height level was removed from each and reduced to ¾-inch discs. As was hoped, compression wood was present in large amounts and in well-defined areas. These areas were delineated, together with zones of opposite and side wood, using the procedure followed by Watson and Dadswell (1957) (fig. 4).

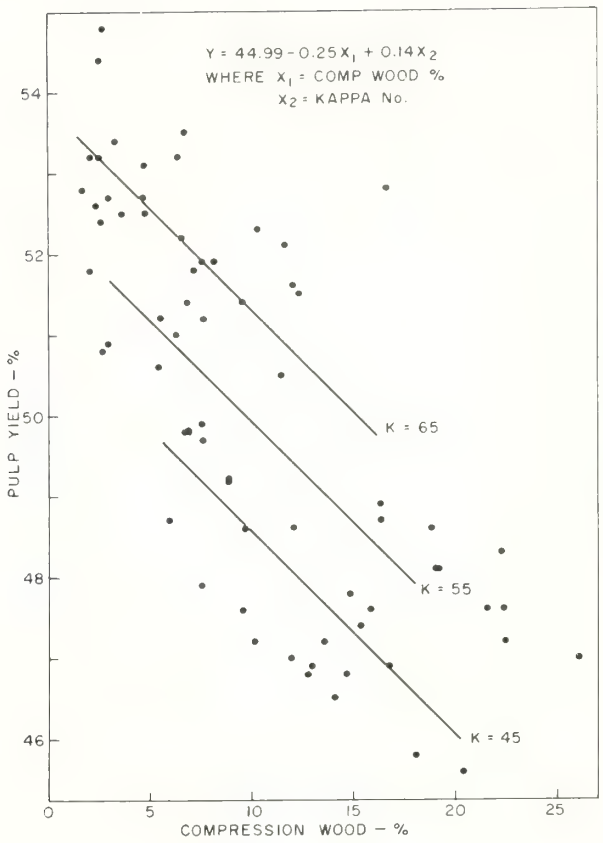

FIGURE 3. — Pulp yield and compression wood for pulps cooked to different lignin contents.

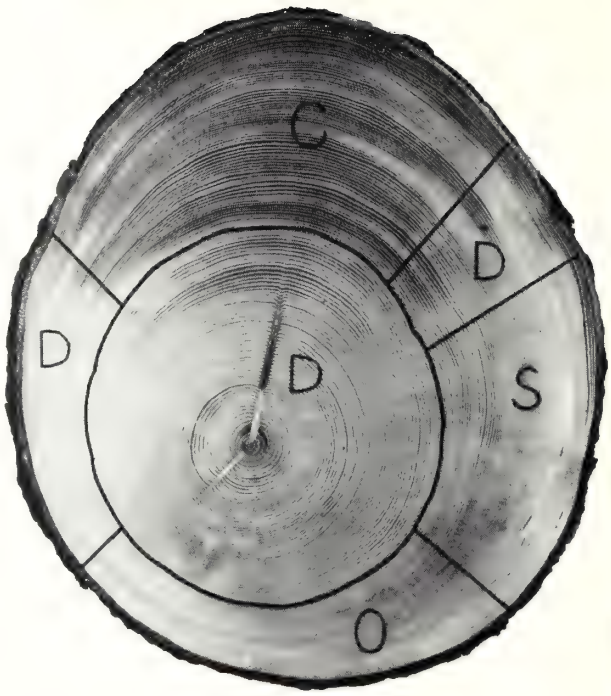

FIGURE 4. — Delineation of discs for pulp and papermaking tests. *C* is taken to be 100-percent compression wood. *S* (sidewood) and *O* (opposite wood) are taken as no compression wood; these were combined to give "normal" or control fraction. *D* is discarded as containing varying amounts of compression wood.

A comparison of chemical and morphological characteristics for the three zones and for control material obtained from the mature wood of a defect-free tree shows that the compression wood zone has a relatively high lignin content, is somewhat lower in pentosans, and displays a markedly higher specific gravity (table 2). These results generally agree with those obtained by other workers. Pillow *et al.* (1935), for example, reported a lignin content of 35.2 percent for the compression wood of loblolly pine (*Pinus taeda* L.) compared to 28.3 percent for normal wood, with pentosans at 12.2 percent compared with 12.4 percent. That compression wood chips, after conditioning and before pulping, tend to equilibrate at a higher moisture content is of some general interest (table 2). The overall mean fiber lengths in the compression and side wood bands were statistically identical, and each was significantly less than the length in the opposite wood zone.

Pulp and papermaking trials were carried out first on pure samples from the three zones. Cooking procedure was essentially the same as that described above. When the trials showed that paper characteristics from the side and opposite wood zones were essentially the same, the chips from the two latter zones from all three trees were combined to form a fraction which was termed "normal" wood. Chips from the compression wood zones from all three trees were similarly pooled. Chips from normal and compression wood were then mixed to give a series of fractions containing different proportions of compression wood on a percentage ovendry weight basis. Percentage dry weight values were later converted to percentage dry volume values by assuming a specific gravity of 0.53 for compression wood and 0.40 for normal wood.

The fractions containing 0-, 5-, 10-, and 100-percent compression wood (by weight) were pulped over a range of cooking times and Kappa numbers. Due to lack of material, only a single cook to give a Kappa number of 80 was made of the 20-, 30-, 40-, and 50-percent compression wood fractions. All pulps were beaten in a PFI mill over a series of predetermined number of revolutions; handsheets were prepared and strength tests carried out according to Tappi Standard T-220 m-60.

Figure 5 shows values for tear, burst, and tensile strength (breaking length) of handsheets from pulps beaten to 350 CSF plotted against percent compression wood by volume. Figure 6 shows strength values expressed as a percentage of those

Table 2.--Miscellaneous characteristics of fractions from black spruce trees with high compression wood content

Sample	Pento-sans	Lignins	Conditioned E.M.C.[1/]	Specific gravity	Tracheid length: Mean	Tracheid length: Standard deviation	Tracheid length: Coefficient of variation
	(Percent)		(Percent)		(mm.)	(mm.)	(Percent)
Opposite wood	7.6	25.2	8.8	0.408	3.47	0.29	8.3
Side wood	7.4	25.3	8.6		2.98	.78	26.1
Compression wood	7.2	31.1	9.2	.528	3.08	.13	4.1
Control	7.3	27.0	8.6	.396	3.40	.56	16.3

[1/] Equilibrium moisture content: the moisture content attained by wood under given conditions of temperature and humidity.

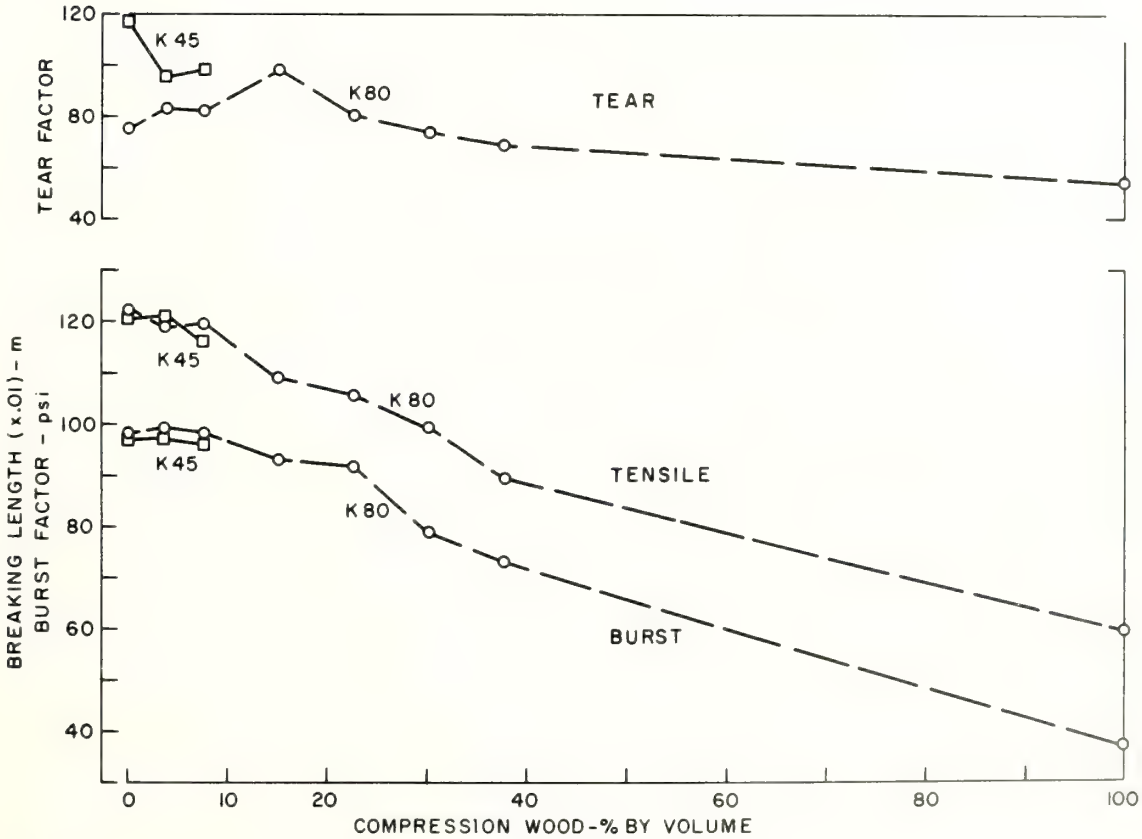

FIGURE 5. — Compression wood content and paper strength.

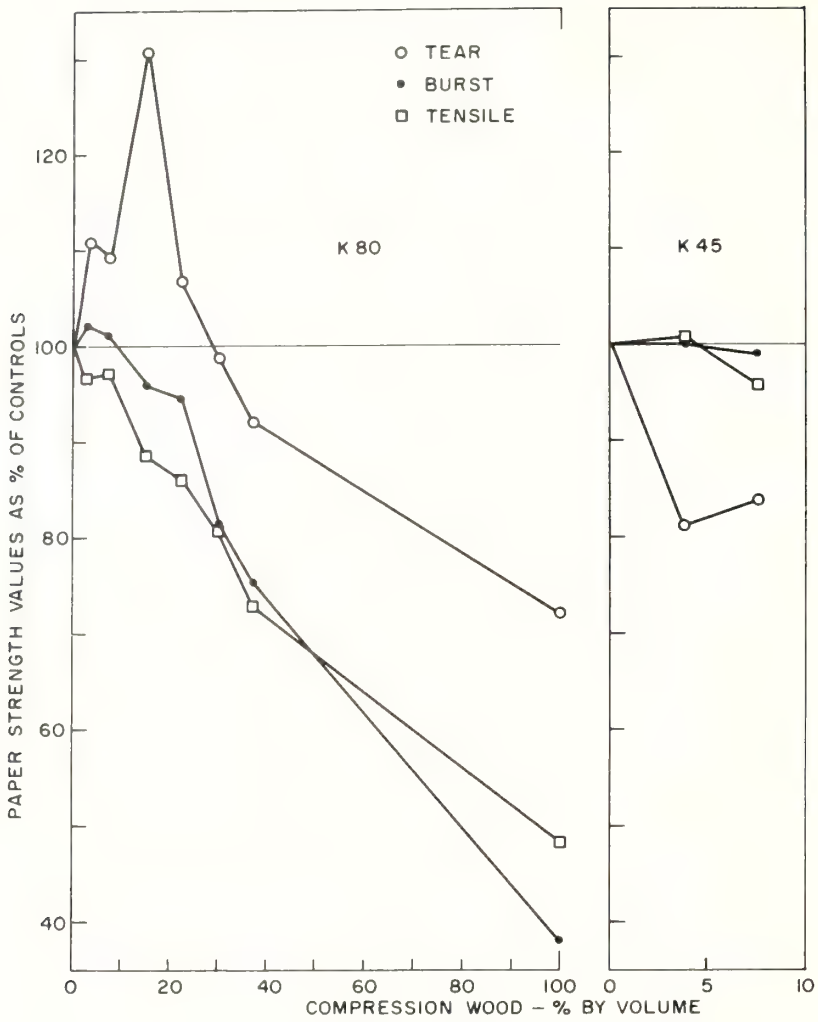

FIGURE 6. — Compression wood and paper strength values expressed as a percentage of the control values.

given by the normal wood fraction. All fractions were cooked to a Kappa number 80, but only three fractions were cooked to the lower Kappa number 45.

Tensile strength of paper made from the pulps cooked to a Kappa number 80 decreased steadily with increasing compression wood content, with pure compression wood having a tensile strength half that of the normal wood used as control. The effect of compression wood when present in the average amount indicated by the investigation discussed earlier — that is, approximately 15 percent by volume — would be to reduce tensile strength by 12 percent. With longer cooking times and Kappa numbers lower than 80, the reduction in tensile strength would be greater than this.

Compression wood in amounts up to about 10 percent appeared to have a beneficial effect on burst strength; the effect, however, disappeared with a longer cook and a lower Kappa number. Compression wood content of 15 percent resulted in a 4-percent decrease in burst strength with the Kappa number 80 pulps. Extrapolation indicated that in the Kappa number 45 pulps the detrimental effect would be even less than this.

The results of the tear tests present some anomalies, with the 15-percent compression wood fractions from the Kappa number 80 pulp giving a tear strength 30 percent greater than the control. It may be that at high Kappa numbers compression wood in small amounts enhances tear strength, but, on the other hand, the results from the Kappa number 45 pulp indicate a 20-percent loss in tear strength. It is felt that this aspect of the results should be treated with reserve.

In summation, these admittedly limited studies indicate that, with the possible exception of tear strength, the strength properties of paper will not

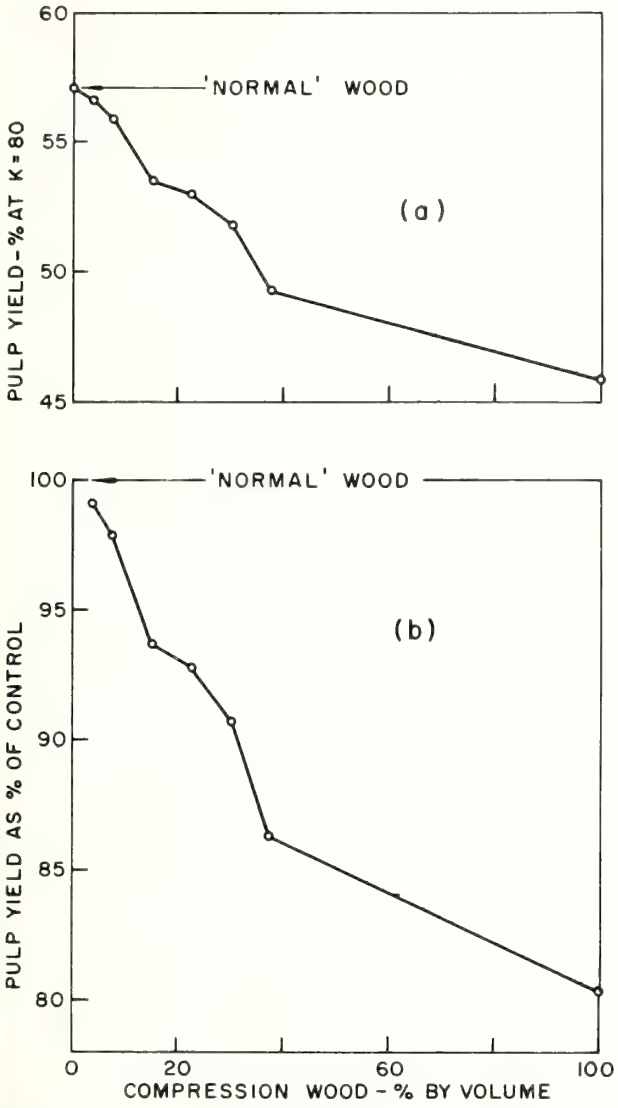

FIGURE 7. — (a) Compression wood content and screened pulp yield; (b) compression wood content and screened pulp yield expressed as a percentage of the yield from "normal" wood.

be affected adversely to an excessive degree by the presence of compression wood in the amounts normally encountered.

The effect on yield, however, could be significant. Screened pulp yields are plotted against compression wood percent in figure 7a, and yield expressed as a percentage of that obtained from the normal compression wood free fraction is plotted in figure 7b. Data presented earlier suggest that 15 percent is not an unrealistic value for the relative amount of compression wood in a stand. This would result in a loss in (chemical) pulp yield of over 6 percent. It would appear then that in a stand of 120-year-old black spruce on a medium site (Site Class 2, Plonski 1956) yielding 2,700 cubic feet or 34 tons of merchantable wood per acre, the loss resulting from the presence of compression wood might be as much as 1 ton per acre, or over 600 tons of usable pulp per square mile.

A more detailed account of this work will appear elsewhere in due course.

Summary

A point sampling system was used to measure the amount of compression wood in over 400 discs from 11 mature black spruce trees grown on a good lowland site in Challies Township, Ontario. Overall mean compression wood content in the 11 trees was found to be 13.9 percent by volume, with mean values in individual trees varying from 5.3 to 26.1 percent. Compression wood content tended to be higher at the base and in the upper crowns of trees. Correlation coefficients were calculated between mean compression wood content for trees and content at each of nine levels within trees. For all except the topmost level sampled, the coefficients were highly significant and ranged between +0.788 and +0.961, indicating strong uniformity of content within trees.

The accuracy of the point sampling method for the determination of compression wood content was confirmed by (sulfite) pulping trials on 68 samples, which showed that compression wood percent and pulp yield were closely correlated ($r=-0.745^{***}$). Other trials indicated that while compression wood present in normal amounts does not result in a serious reduction in paper strength, pulp yields might be reduced by as much as 6 percent. Calculations based on known yields from black spruce stands of the commonest site class showed that reduction in pulp yields of this order would result in a loss of about 1 ton of usable fiber per acre.

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Shrinkage and Footage Loss from Drying 4/4-Inch Hard Maple Lumber

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Shrinkage and Footage Loss From Drying 4/4-Inch Hard Maple Lumber

Daniel E. Dunmire

When wood dries, it shrinks appreciably tangentially and radially to the grain. Longitudinal shrinkage is almost negligible and can be disregarded when the lumber has normal end trimming allowance. However, tangential and radial shrinkage is important to lumber processors because it affects the utility of their lumber. If air-dry lumber is scant in thickness and width, it may not be possible to cut parts of specific dimension from the lumber after it is kiln-dried. Most hardwood product processors know this, and some have rules of thumb to determine if a package of air-dry lumber will, after kiln-drying, meet their needs for thickness and width.

Methods have been published for estimating wood shrinkage (MacLean 1945, Peck 1960, Rietz 1941),[1] but they are based on data from small, clear samples of wood dried under controlled laboratory conditions. Commercial lumber consists of boards of different widths and lengths with various defects, and of different grain patterns. All of these factors affect shrinkage during drying.

This paper shows how to calculate the shrinkage that can be expected when drying commercial hard maple lumber.

PROCEDURE

First, we learned how cutting yield varies within grades of lumber by studying the dimension and yield characteristics of about 100,000 board feet of hard maple lumber at 20 sawmills in 10 states throughout the hard maple producing region. With this knowledge to aid us, we graded, selected, and purchased 1,588 4/4-inch-thick, air-dried hard maple (*Acer saccharum* and *A. nigrum*) boards totaling 10,581 board feet for our study.[2] The lumber was selected from all commercial board widths and lengths of the best five grades of hard maple lumber (table 1). Within lumber grades, the boards were classified into 10-percent cutting yield classes.

After selection, an inspector from the National Hardwood Lumber Association (NHLA) measured the lumber with a board rule and graded it to verify our board grades. We also measured the width of each board to the nearest ¼ inch at a point one-third the length from the narrow end of each board, where the surface measure of tapered boards is measured. Lumber lengths were measured in the same manner as standard lengths (NHLA 1960).

Then the lumber was kiln-dried, equalized, and conditioned in a 6,000-board-foot-capacity, forced-air dry kiln, using FPL drying schedule T8-C3 (Rasmussen 1961). Drying results were normal (fig. 1). Based on 20 kiln samples and other moisture meter readings, the average moisture content (MC) was 13 percent prior to drying and 6 percent after drying. The difference between the original and final MC, 7 percent, is referred to hereafter as the drying range (DR).

The lumber was then regraded and volume was remeasured with a board rule by an NHLA inspector. Each board was also classified as plainsawed, bastardsawed, or quarter-

[1] *Names and dates in parentheses refer to Literature Cited.*

[2] *This lumber was obtained to determine the cutting yields of hard maple lumber in a joint study with the Forest Products Laboratory (FPL), Madison, Wis., and has been used since then for several related studies.*

Table 1. — Number of 4/4 hard maple boards and their surface measure by grade, by length, width, and yield class, and by saw type

Item	Number of boards by grade						Surface measure (in bd. ft.) of boards by grade					
	FAS	Sel	No. 1 Common	No. 2 Common	No. 3A Common	Total	FAS	Sel	No. 1 Common	No. 2 Common	No. 3A Common	Total
Length class (feet)												
4- 5	--	--	56	62	68	186	--	--	153	150	164	467
6- 7	--	30	65	57	51	203	--	133	262	202	177	774
8- 9	24	32	68	73	64	261	154	184	369	369	313	1,389
10- 11	24	32	69	78	52	255	184	226	479	513	297	1,699
12- 13	24	32	69	76	62	263	218	270	552	613	442	2,095
14- 15	24	30	67	58	39	218	250	279	656	512	311	2,008
16	24	28	62	53	35	202	295	295	693	506	360	2,149
Width class (inches)												
3- 4	--	25	82	93	70	270	--	102	290	312	214	918
5- 6	30	40	98	112	113	393	186	217	488	561	532	1,984
7- 8	30	42	98	109	119	398	241	303	639	691	749	2,623
9- 10	30	41	94	88	59	312	294	371	774	708	454	2,601
11- 12+	30	36	84	55	10	215	380	394	973	593	115	2,455
Yield class (percent)												
31- 40	--	--	--	--	13	13	--	--	--	--	66	66
41- 50	--	--	--	5	84	89	--	--	--	24	487	511
51- 60	--	--	--	65	122	187	--	--	--	410	731	1,141
61- 70	--	--	55	175	103	333	--	--	407	1,077	544	2,028
71- 80	--	--	168	154	39	361	--	--	1,181	995	195	2,371
81- 90	40	71	170	52	6	339	371	598	1,153	329	32	2,483
91-100	80	113	63	6	4	266	730	789	423	30	9	1,981
Lumber saw type[1/]												
Plainsawed	92	123	329	342	198	1,084	763	809	1,961	1,909	986	6,428
Bastardsawed	26	56	121	103	130	436	316	540	1,168	871	823	3,718
Quartersawed	2	5	6	12	43	68	22	38	35	85	255	435
Total	120	184	456	457	371	1,588	1,101	1,387	3,164	2,865	2,064	10,581

[1/] Average annual ring slope in degrees and the range by lumber grade (in parentheses) were as follows: Plainsawed, 16.9 (16.3-17.8); bastardsawed, 40.5 (39.1-41.5); quartersawed, 73.6 (71.1-80.0); all board types, 25.8 (16.3-80.0).

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FIGURE 1. — Some stress-free sections of kiln samples from kiln charge No. 1.

sawed[3] by MacLean's (1945) method whereby the average slope, measured in degrees, of four annual rings on the cross-section of a board is determined. Of the study boards, 68 percent were plainsawed, 28 percent bastardsawed, and 4 percent quartersawed (table 1).

Because longitudinal shrinkage of wood is negligible (Koehler 1954), board lengths were not remeasured. But we remeasured board widths to the nearest ¼ inch as we had done before drying. Using these measured air-dried and kiln-dried board widths and the air-dried board lengths we calculated to the nearest hundredth board foot the air-dry and kiln-dry footage for each board. The results, "calculated board measure," are compared in the next sections with the board footages obtained by the lumber inspector, "board rule measure."

RESULTS

Total width shrinkage of all boards ($\overline{DR}$= 7 percent MC) was 343 inches, 2.8 percent of the combined widths; shrinkage ranged from 2.7 to 2.9 percent by grade and from 2.3 to 3.0 percent by board type. As would be expected, plainsawed lumber shrank more than bastardsawed or quartersawed lumber (table 2).

Total losses in calculated board measure of all boards were 274 board feet, 2.6 percent of the original footage (table 3). By grades, shrinkage ranged from 2.5 to 2.7 percent, but by saw type it ranged from 2.3 to 2.8 percent. Losses were greatest in plainsawed lumber.

Total surface footage of the lumber before kiln-drying was practically the same by both the board rule measure (10,581 board feet) and the calculated board measure (10,571 board feet). However, footage loss determined by board rule (176 board feet) was considerably less than that based on calculated board measurements (274 board feet) (table 3). Although the board rule is the accepted means of measuring lumber for buying and selling, it apparently does not accurately account for footage loss due to drying.

We used the calculated board measure data rather than the board rule measure to derive a set of equations[4] for predicting surface area losses due to kiln-drying hard maple lumber. Since wood shrinkage, for practical purposes, has been found to be directly proportional to its moisture content below fiber saturation point (Rasmussen 1961), our estimating equations may be applied through any drying range below the wood fiber saturation point, which is about 30 percent MC for hard maple.

Board width data, before and after kiln drying, were of course used to derive equations for calculating width losses.

(Warning: Estimates of footage lost in shrinkage, when using these equations, will not equal estimates obtained with a board rule. Equation estimates are more accurate. This will be discussed in the section on Equation Accuracy.)

[3] *A plainsawed hardwood board has annual rings oriented at slopes of 0 to 30 degrees, bastardsawed 31 to 60 degrees, and quartersawed 61 to 90 degrees with the face of the board (USFS, Forest Prod. Lab. 1950).*

[4] *Consultation was with Thomas H. Starks, Ph. D., Associate Professor of Mathematics, Southern Illinois University, Carbondale, Illinois, at which time a suitable computer program was chosen (Fitzpatrick 1965).*

Table 2. — Actual and estimated board width and shrinkage due to kiln drying 4/4-inch-thick hard maple lumber from 13 to 6 percent moisture content

Lumber grade or board type	Cumulative board width				Estimated shrinkage[1]	
	Air-dried	Kiln-dried	Actual shrinkage			
	Inches	Inches	Inches	Percent	Inches	Percent
BY LUMBER GRADE						
FAS	1,097	1,065	32	2.9	30	2.7
Sel	1,507	1,464	43	2.9	41	2.7
No. 1 Common	3,667	3,564	103	2.8	100	2.7
No. 2 Common	3,385	3,292	93	2.7	93	2.7
No. 3A Common	2,555	2,483	72	2.8	70	2.7
BY BOARD TYPE						
Plainsawed	7,623	7,395	228	3.0	224[2]	2.9
Bastardsawed	4,074	3,971	103	2.5	96[3]	2.4
Quartersawed	514	502	12	2.3	12[3]	2.3
Total or average	12,211	11,868	343	2.8	334[1]	2.7

[1] Shrinkage estimated from equation $S = 0.391 \overline{DR} W_o$.
[2] Shrinkage estimated from equation $S = 0.419 \overline{DR} W_o$.
[3] Shrinkage estimated from equation $S = 0.338 \overline{DR} W_o$.

Table 3. — Actual and estimated footage loss due to kiln-drying 4/4-inch-thick hard maple lumber from 13 to 6 percent moisture content

Lumber grade or board type	Board rule measure				Calculated board measure				Estimated footage loss	
	Air-dried	Kiln-dried	Actual shrinkage		Air-dried	Kiln-dried	Actual shrinkage			
	Board feet	Board feet	Board feet	Percent	Board feet	Board feet	Board feet	Percent	Board feet[1]	Percent
BY LUMBER GRADE										
FAS	1,101	1,085	16	1.5	1,103	1,075	28	2.5	30	2.7
Sel	1,387	1,363	24	1.7	1,382	1,345	37	2.7	38	2.7
No. 1 Common	3,164	3,116	48	1.5	3,171	3,086	85	2.7	87	2.7
No. 2 Common	2,865	2,812	53	1.8	2,858	2,787	71	2.5	78	2.7
No. 3A Common	2,064	2,029	35	1.7	2,057	2,004	53	2.6	56	2.7
BY BOARD TYPES										
Plainsawed	6,428	6,315	113	1.8	6,426	6,248	178	2.8	188[2]	2.9
Bastardsawed	3,718	3,663	55	1.5	3,712	3,626	86	2.3	88[3]	2.4
Quartersawed	435	427	8	1.8	433	423	10	2.3	10[3]	2.3
Total	10,581	10,405	176	1.7[4]	10,571	10,297	274	2.6[4]	289[1]	2.7[4]

[1] Shrinkage estimated from equation $\overline{FL} = 0.391 \overline{DR} V_c$.
[2] Shrinkage estimated from equation $\overline{FL} = 0.419 \overline{DR} V_o$.
[3] Shrinkage estimated from equation $\overline{FL} = 0.338 \overline{DR} V_o$.
[4] Average.

These equations are:

$$S = 0.391\ \overline{DR}\ W_o \quad (1)$$

$$W_o = W_r / [1 - (0.391\ \overline{DR})] \quad (2)$$

$$\overline{FL} = 0.391\ \overline{DR}\ V_o \quad (3)$$

$$V_r = [1 - (0.391\ \overline{DR})]\ V_o \quad (4)$$

where S = total shrinkage in inches of width for all boards in a lumber package due to drying, $S = W_o - W_r$.

$\overline{DR}$ = any drying range between 30 percent and 0 percent moisture content, expressed as decimals, through which the lumber is dried. The original moisture content minus the final moisture content of the lumber is $\overline{DR}$. Because wood does not shrink until it is dried to the fiber saturation point, an MC of 30 percent should be used in places of the original MC in computing the $\overline{DR}$ for any hard maple above fiber saturation point.

W_o = total original or air-dried width in inches of all boards in a lumber package before drying.

W_r = total residual width in inches of all boards in a lumber package after drying and conditioning the lumber.

$\overline{FL}$ = footage loss in board feet of all boards in a lumber package due to drying. $\overline{FL}$ is the footage loss due to lumber shrinkage; $\overline{FL} = V_o - V_r$.

V_o = total board feet of a lumber package before drying.

V_r = total residual board feet of lumber after drying and conditioning.

Shrinkage did not differ by lumber grades or cutting yield classes but did differ by board type. Thus, for lumber with specific grain orientation, the equations should be modified. Furthermore, because our quartersawed lumber was not a good sample[5], its shrinkage was the same as for the bastardsawed lumber. Thus, the derivation of the bastardsawed equations included shrinkage values from the quartersawed lumber. The modified equations for plainsawed and bastardsawed lumber saw types are:

For plainsawed lumber
(0-30 degrees)

$$S = 0.419\ \overline{DR}\ W_o \quad (1)$$

$$W_o = W_r / [1 - (0.419\ \overline{DR})] \quad (2)$$

$$\overline{FL} = 0.419\ \overline{DR}\ V_o \quad (3)$$

$$V_r = [1 - (0.419\ \overline{DR})]\ V_o \quad (4)$$

For bastardsawed lumber
(31-60 degrees)

$$S = 0.338\ \overline{DR}\ W_o \quad (1)$$

$$W_o = W_r / [1 - 0.338\ \overline{DR}] \quad (2)$$

$$\overline{FL} = 0.338\ \overline{DR}\ V_o \quad (3)$$

$$V_r = [1 - (0.338\ \overline{DR})]\ V_o \quad (4)$$

[5] *The quartersawed lumber was not a good sample because there were not enough boards in that class, most of the boards were cut from near the center of logs (62 percent contained pith), and most of these boards (81 percent) were No. 2 and No. 3A Common grades.*

APPLYING THE EQUATIONS

Lumber shrinkage estimating equations are most useful for kiln loads, truck loads, or carload lots of hard maple lumber; but they also predict the average shrinkage of individual boards.

Equation (1) is used when an estimate of average shrinkage (S) in board width is desired. To determine shrinkage accurately, board widths must be measured precisely. For commercial lumber, widths should be measured to the nearest ¼ inch. Shrinkage curves for board widths dried through various drying ranges and derived from equation (1) are shown in figure 2.

Equation (2) is useful in predicting the air-dry board width that will be needed when the required kiln-dry width is known. Figure 3, based on this equation, is useful for making these predictions.

Equation (3) is used when losses in surface measure ($\overline{FL}$) due to lumber shrinkage are desired. Total original footage (V_o) may be the board rule measure of the lumber, but it can be determined more precisely by calculating and adding the surface measure of individual boards.

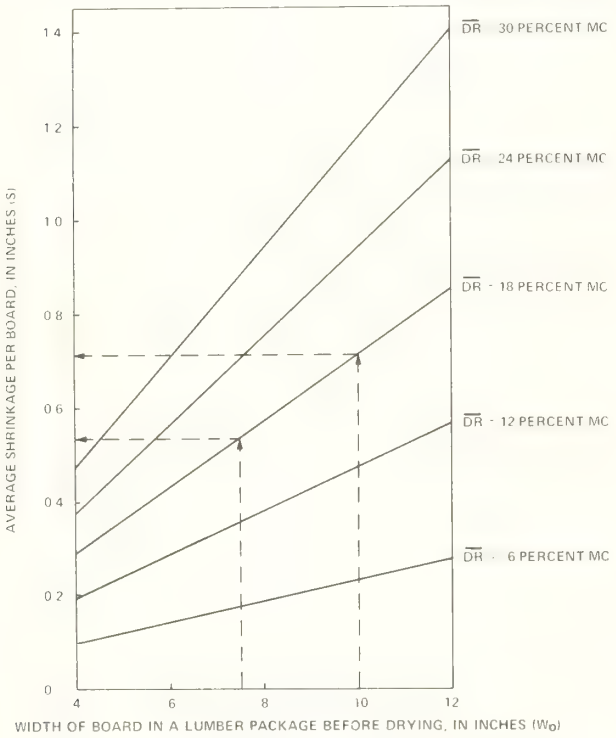

FIGURE 2. — Shrinkage in average board widths of 4/4 hard maple lumber dried through various drying ranges; derived from equation $S = 0.391 \overline{DR} W_o$. As an example assume an original board width (W_o) of 10 inches, an original moisture content (MC) of 50 percent, and a final MC of 12 percent. $\overline{DR}$ is the difference between the original and final MC; but whenever the original MC is higher than the fiber saturation percent (30 percent for hard maple), then the fiber saturation percent is used. Therefore $\overline{DR} = 30\text{-}12$ or 18 percent. Following the arrowed lines in the chart, a 10-inch-wide board dried through a range of 18 percent will shrink 0.7 inch. Likewise a 7.5-inch-wide board with an 18-inch $\overline{DR}$ will shrink 0.53 inch.

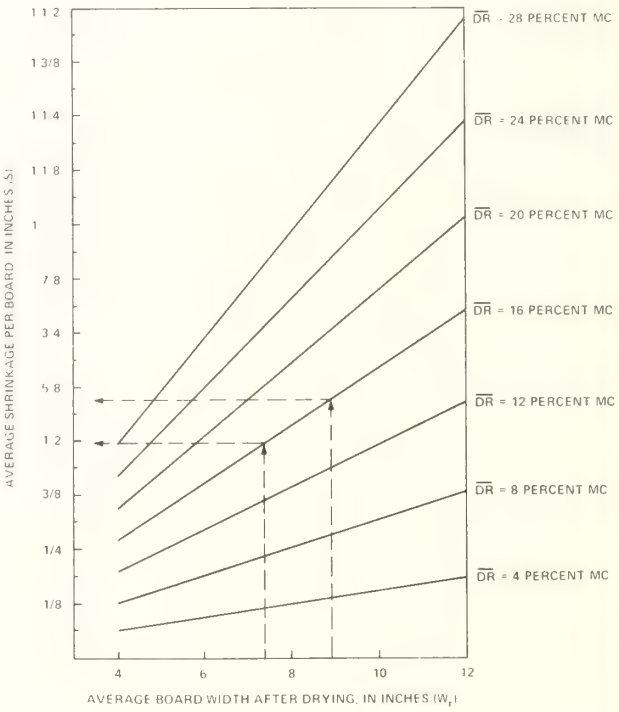

FIGURE 3. — Graph for predicting what the air-dry board width must be to achieve a given kiln-dry board width; derived from equation $W_o = W_r / [1 - 0.391 \overline{DR}]$. As an example assume that a kiln-dry board width of 9 inches is needed, that the initial MC of boards will be 24 percent, and that the kiln-dry MC will be 8 percent. $\overline{DR}$ then is 16 percent. By following the arrowed lines in the chart, we find that a kiln-dry width of 9 inches requires an air-dry board nearly ⅝ inch wider or about 9⅝ inches. Likewise, a kiln-dry width of 7½ inches will require an air-dry board ½ inch wider (8 inches).

Equation (4) can be used to estimate total residual lumber footage (V_r) after drying. If the lumber is measured with a board rule, the footage will not equal V_r, which is based on more acurate measurements (table 4). Furthermore, figure 4 may be used to predict V_r.

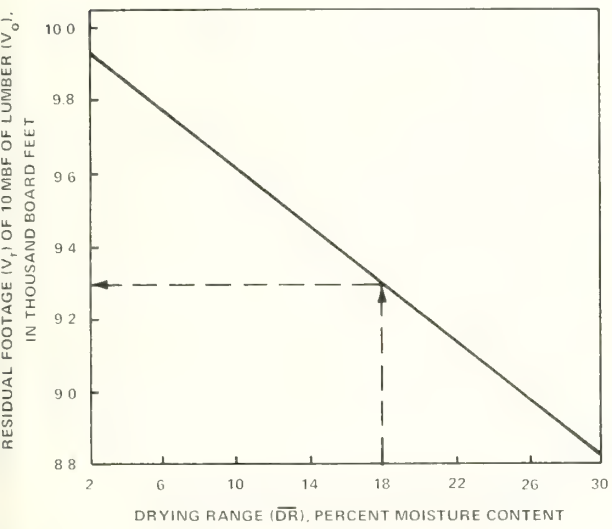

FIGURE 4. — Graph for predicting residual footage after drying 4/4 hard maple lumber; derived from equation $V_r = [1 - (0.391\ \overline{DR})]\ V_o$. As an example, assume an initial volume of 9.0 thousand board feet, an initial MC of 28 percent and a final MC of 10 percent. $\overline{DR}$ then is 28 — 10 or 18 percent. By following the arrowed lines in the chart, we find that at a drying range of 18 percent, the residual footage of 10 thousand board feet is 9.3 thousand. The residual footage of 9 thousand board feet would be 9/10 x 9.3 or 8.37 thousand. Using equation (4), the residual footage would be 8.367 thousand.

A question often asked in the industry is this, "If maple lumber is shipped air-dried, then kiln-dried in transit and inspected, how much footage should the buyer pay for on an air dried basis?" Equation (4) solved for the original volume, $V_o = V_r / [1 - (0.391\ \overline{DR})]$, will give an air-dried footage approximation. However, V_r should be obtained by the calculation method as shown in the last column of table 4.

Moreover, these equations can be adapted for use with automatic data processing equipment. If green boards were machine-measured on the green chain at a mill, immediate dry measurements could be estimated by a computer. This might eliminate the need of remeasuring seasoned boards.

The shrinkage equation (1) can also be modified easily for use with shrinkage rates (values) in table 39 of the *Wood Handbook* (USFS, Forest Prod. Lab. 1955). The derivation follows:

$S = K\ \overline{DR}\ W_o$ where K is a constant

$$\overline{SR} \quad \frac{S}{W_o} = \frac{K\ \overline{DR}\ W_o}{W_o}$$

where $\overline{SR}$ is shrinkage rate

$\overline{SR} = K_1\ \overline{DR}$

where K_1 is modified constant for *Wood Handbook* shrinkage rates

$K_1 = \overline{SR}/\overline{DR}$

For example:

$$K_1 = \frac{0.054}{0.24} = 0.225$$

for quaking aspen, tangential grain (0-45 degrees), dried to 6 percent MC from the green condition (30 percent MC)

and:

$$K_1 = \frac{0.032}{0.24} = 0.133$$

for yellow-poplar, radial grain (45-90 degrees), dried to 6 percent MC from the green condition

These modified constants are substituted in lieu of our equation constants. Equation use, however, should be limited to dimension and cut stock, like flooring, because they have not been tested for lumber stock of species other than hard maple.

Table 4. — An example: total residual board measure is accurately estimated from total original board measure

Number of boards	Board sizes: Original	Board sizes: Residual[1/]	Board rule method: V_o	Board rule method: V_r	Calculation method: V_o	Calculation method: V_r
	Inches Feet	Inches Feet	Board feet		Board feet	
5	4 x 10	3.81 x 10	15	15	16.7	15.9
7	5 x 12	4.77 x 12	35	35	35.0	33.4
3	8 x 16	7.62 x 16	33	30	32.0	30.5
4	10 x 14	9.53 x 14	48	44	46.7	44.5
6	6 x 13	5.72 x 13	39	36	39.0	37.2
Total			170	160*	169.4	161.5**

NOTES ON CALCULATIONS:

If $\overline{DR}$ is 12 percent MC, total residual board measure may be estimated quickly by equation $V_r = \left[1 - (0.391\ \overline{DR})\right] V_o$, as follows:

A. If total V_o is 170 (board rule method), V_r is 162*

B. If total V_o is 169.4 (calculation method), V_r is 161.5**

Answer to "B" indicates that estimated V_r = calculated V_r.

Other example problems would show that calculated and estimated methods would give approximately the same answers. Board rule method gives less accurate answers.

[1/] Residual board widths are determined from $W_r = \left[1 - (0.391\ \overline{DR})\right] W_o$; $\overline{DR}$ = 12% MC.

* Compare board rule V_r with equation V_r.

** Compare calculated V_r with equation V_r.

EQUATION ACCURACY

Shrinkage and footage losses can be predicted within ± 0.1 percent of the cumulative width and calculated surface measure of hard maple lumber. We discovered that estimated shrinkage and footage losses occurring through a drying range of 7 percent moisture content are 2.9 percent for plainsawed lumber, 2.4 percent for bastardsawed lumber, and 2.7 percent for both types combined (table 3).

The shrinkage rates observed in this study are somewhat greater than those reported in the *Wood Handbook* (USFS, Forest Prod. Lab. 1955) (fig. 5). *Wood Handbook* shrinkage rates for sugar maple dried through a range of 7 percent moisture content are 2.2 percent tangentially and 1.1 percent radially. These rates differ from our rates because *Wood Handbook* data are based on the average shrinkage of small, clear, square, flat wood specimens; but our rates are for hardwood lumber, which rarely has straight and square edges, and consists of boards of a variety of sizes and with many kinds of defects.

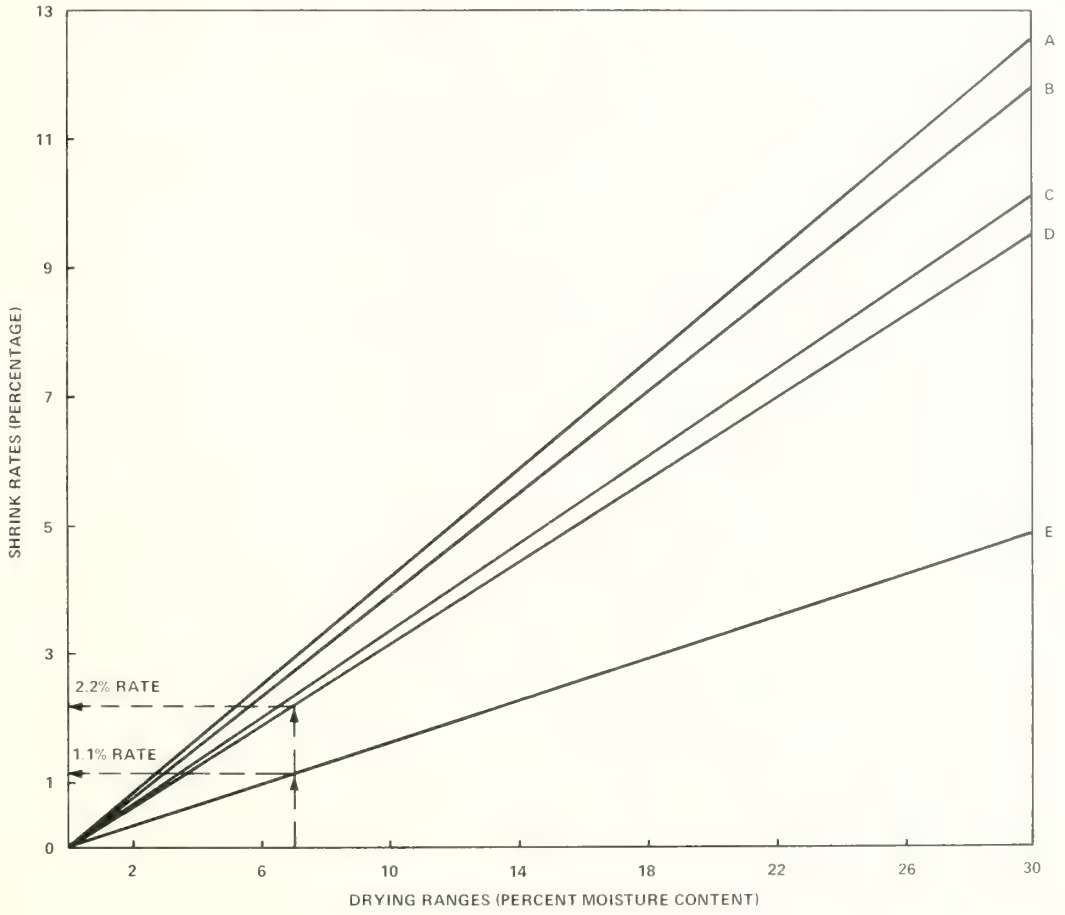

FIGURE 5. — Relationship of estimated and WOOD HANDBOOK shrinkage rates of hard maple lumber dried through various drying ranges. A, plainsawed type ($S = 0.419\ \overline{DR}\ W_o$) (0-30 degrees; B, plainsawed type ($S = 0.391\ \overline{DR}\ W_o$) (0-45 degrees); C, bastardsawed type ($S = 0.338\ \overline{DR}\ W_o$) (31-60 degrees); D, tangential grain (WOOD HANDBOOK) (0 degrees); E, radial grain (WOOD HANDBOOK) (90 degrees).

About 5 percent of all study boards were cupped slightly after kiln-drying. This normal warping probably caused decreased dry width measurements, resulting in increased shrinkage rates. Moreover, our board widths were measured ". . . to the nearest ¼ inch. . .," which were crude measurements for determining shrinkage but refined measurements for calculating footage. An example of this is shown in table 3, wherein the total actual shrinkage by the board rule measure was 98 board feet less than the calculated or more accurate board measure.

Predicting footage lost in shrinkage is complicated because the board rule method, although practical, is crude, especially when board widths are near the ½-board-foot mark on the board rule. For example, a sawmill operator can saw 12-foot-long boards to widths between 5 and 5½ inches, knowing that they will scale 5 board feet after drying, since none of the boards would shrink below 4½ inches. On the other hand, most 12-foot-long boards that are sawed between 4½ and 4¾ inches, when dried, will scale 4 board feet. Thus, for prediction purposes, calculated footage tallies are preferable.

Upon first glance, a reader might doubt that the total original (before drying) volume of a batch of boards of widely varying widths and lengths can be used to determine footage lost during drying. Table 4 is an example that indicates the equation method will work.

Our equations can be modified, of course, to predict shrinkage and footage losses in other lumber species. To do so requires studies of shrinkage in other species.

We used the hard maple equation to estimate shrinkage of nutmeg (*Dialyanthera virola*) lumber (Rice 1966). The actual shrinkage was about 0.6 percent less than estimated with the equation; hard maple lumber shrinks more than nutmeg lumber.

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TOPOGRAPHY & SOIL RELATIONS for WHITE and BLACK OAK IN SOUTHERN INDIANA

Peter R. Hannah

NORTH CENTRAL FOREST EXPERIMENT STATION
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Topography and Soil Relations for White and Black Oak in Southern Indiana[1]

Peter R. Hannah

Numerous papers have been written on soil-site relations for upland oaks in various sections of the eastern deciduous forest (Carmean 1965, 1968; Della-Bianca and Olson 1961; Doolittle 1957; Einspahr and McComb 1951; Gaiser 1951; Gysel and Arend 1953; McClurkin 1963; McGahan *et al.* 1961; Schnur 1937; Trimble and Weitzman 1956). This paper describes the soil-site relations of white (*Quercus alba* L.) and black oaks (*Quercus velutina* Lam.) on unglaciated soils of the Norman and Crawford uplands in southern Indiana. These uplands occupy approximately 5,000 sq. miles (13,000 sq. km.) in 19 counties.

The gray-brown podzolic soils of the southern Indiana uplands are derived from sandstones and shales of Mississippian and Pennsylvanian age and varying amounts of wind-deposited silts (loess). Zanesville, Tilsit, Muskingum, and Wellston are the most important forest soils in the region, and all sample plots were established on these series. Some soils of limestone origin do occur in the uplands but were not included in the sample. Zanesville and Tilsit are common soil series on the loess-covered broad upland ridges and gentle slopes. These series usually have fragipan layers that occur between 26 and 42 inches below the surface; the soils are moderately well-drained to well-drained. The Muskingum and Wellston soil series, common on steeper slopes, represent a wide range of soil depth, stoniness, and texture, and are both classified as well-drained to excessively drained.

METHODS

Study plots were located only in fully stocked, undisturbed, even-aged stands of mixed oaks or mixed hardwoods. Of the 146 fifth-acre plots established, white oak was measured on 126 and black oak on 86. Stand ages ranged from 28 to 106 years, and site index, estimated from curves by Schnur (1937), ranged from 38 to 86 for white oak and 42 to 94 for black oak. Within each plot total height and total age (age at 4½ feet plus 2 years) were determined from at least four dominant and codominant free-growing trees of each species present.

In addition, the following information was obtained on each study plot: Soil profiles were described and soil types identified. The thickness of the A horizon (A1 + A2 horizons) was measured in 12 places. Composite soil samples were collected from the major soil horizons in four pits and analyzed for texture (Bouyoucos 1951) and stone content (percent by weight of material greater than 2 mm). Slope aspect, slope position, and slope steepness were the recorded topographic features.

Analysis of Data

Analytical procedures similar to those described by Carmean (1965) were used in this study. The objective was to relate site index to specific soil and topographic features ob-

[1] *Presented before Div. S-7, Soil Science Society of America, Nov. 8, 1967, at Washington, D.C.*

served on the plots. Study plot data for each species were analayzed by multiple regression using the model:

$$\text{Log total tree height} = b_0 + b_1 (1/\text{total age}) + b_2 X_2 + \cdots b_n X_n.$$

This equation describes the relation between total tree height and various coded transformations of tree age, soil, topography, and certain first-order interactions among these features.

First, scatter diagrams were made to observe trends of variables suspected of accounting for substantial variation in a soil-site relationship. Eleven promising variables were arranged in apparent descending order of importance, and R^2 values were computed for all combinations of 1 to 11 variable equations using a step-wise screening program developed by Furnival (1964). An equation containing variables significantly related to tree height was then selected for further refinement. The variables in this equation were fixed in the regression analysis and then additional variables were tested in groups of 11 to determine if they significantly improved the precision of the initial equation. Transformations and interactions tested were those found significant in the study by Carmean (1965) plus those suggested from field experience. Forty-nine transformations were tested for white oak and 27 for black oak.

All retained variables were then tested for significance by analysis of variance. Significant effects and interactions, plus three nonsignificant, but nonetheless important interactions were retained in the equations and coefficients were calculated.

RESULTS AND DISCUSSION

The Equations

The final equations for predicting site index of white and black oak are:

White oak (126 plots): $R^2 = 0.84$

$$\begin{aligned} Y = {} & 2.48209 - 12.42516/X_1 + 0.03026\,X_2 \\ & + 0.00110\,X_3 \\ & - 0.00114\,X_4 + 0.01751\,X_5 - 0.00383\,X_7 \\ & - 1.19984/X_7 \\ & - 0.00137\,X_8 - 3.19761/X_9 - 0.00082\,X_{10} \\ & - 0.00036\,X_{11} \\ & + 0.00010\,X_{12} - 0.00057\,X_{14} - 0.00010\,X_{15} \\ & - 0.00034X_{16} \\ & - 0.00097\,X_{17} \end{aligned}$$

Black Oak (86 plots): $R^2 = 0.85$

$$\begin{aligned} Y = {} & 2.68882 - 23.44295/X_1 - 0.00109X_1 \\ & + 0.03670\,X_2 \\ & - 0.18273/X_2 + 0.00126\,X_3 - 0.00524\,X_6 \\ & - 0.00076\,X_7 \\ & - 0.00108\,X_8 + 0.00035\,X_9 - 0.00056\,X_{11} \\ & - 0.00171\,X_{12} \\ & + 0.00050\,X_{13} - 0.00027\,X_{15} \end{aligned}$$

Where:

Y = Logarithm of total tree height (feet)
X_1 = Total tree age
X_2 = Surface soil (A1 + A2 horizons) thickness (inches)
X_3 = Percent distance to ridge = (distance to ridge/length slope) 100
X_4 = $\lfloor$(sine azimuth from southeast) + 1$\rfloor$ 100
X_5 = Slope shape (convex = 1; linear = 2; concave = 3)
X_6 = Slope steepness (%)
X_7 = Clay content of B2 horizon (%)
X_8 = Clay content of B3, BX, or C horizons (%)
X_9 = Silt content of B1 horizon (%)
X_{10} = Sand content of A2 horizon (%)
X_{11} = Stone content of B2 horizon (%)
X_{12} = $\lfloor$(500 — 10,000/X_1) (100 — X_6)$\rfloor$ 1/100
X_{13} = $\lfloor$(500 — 10,000/X_1) (X_3)$\rfloor$ 1/100
X_{14} = $\lfloor$(500 — 10,000/X_1) (X_9)$\rfloor$ 1/100
X_{15} = (X_2) (X_3)
X_{16} = $\lfloor$(X_2) (300 — X_4)$\rfloor$ 1/10
X_{17} = $\lfloor$(300 — X_4) (100 — X_7)$\rfloor$ 1/100

The standard errors for a single observation at the means of each of the variables are shown in Table 1. Precision of these estimates can be improved if several site observations are made at a particular field location.

Table 1. — Standard error of estimate, standard deviation, and coefficients of multiple determination for the most precise equations computed for white oak and black oak

Item	White oak	Black oak
Number of plots	126	86
Average site index (feet)	66.4	71.8
Average tree age, years	54.0	50.2
Average tree height (feet)	68.2	71.6
Standard deviation of tree heights (feet)	± 12.1	± 12.1
Standard error of estimate of mean tree height (percent)	± 8.16	± 7.99
Coefficients of multiple determination (R^2):		
a. For age, soil, and topographic transformations	.842	.847
b. For age and topographic transformations	.569	.544
c. For age transformations	.368	.336

Approximately 84 percent ($R^2 = 0.84$) of the observed variation in tree height was associated with variations in the factors finally included in the equations; only 37 percent of the variation in tree height for white oak and 34 percent for black oak is associated with variation in tree age.

The equations were used to calculate site prediction tables for field use in the unglaciated uplands of southern Indiana; these have been presented elsewhere (Hannah 1967).

Cause and effect relationships cannot be shown in a random sample lacking experimental controls. Nevertheless, the repeated occurrence of the same variables in this and other soil-site studies (e.g. Carmean 1965, 1968; Doolittle 1957; Einspahr and McComb 1951; Gaiser 1951) — variables that account for a significant amount of observed variation — is a strong indication that we are dealing with variables closely associated with the physical and chemical site requirements for tree growth. The following speculations as to the basic causes for the observed differences in site will be better understood with the help of Figures 1 and 2, which are based on the regression equations and show the relation between site index and the important soil and topographic features.[2]

Depth of Surface Soil

Analysis of preliminary equations indicated that depth of the surface soil (A1 plus A2 horizons) is the most important environmental feature measured. As depth of the surface soil increases, site index for white and black oak increases (Figs. 1A, 1B, 2A, 2D). This trend, over the range of observed conditions, is linear for white oak and slightly curvilinear for black oak, the latter indicating a decline in the rate of site index increase as surface soil becomes deeper. Thickness of the A horizon was an important factor in the Ohio soil-site study by Carmean (1965); and in a study by Doolittle (1957) the A horizon thickness accounted for 91 percent of the variation in site index for oak in the southern Appalachians.

Surface soils on undisturbed oak sites in southern Indiana are loose and porous and generally well aggregated, and contain substantial amounts of incorporated organic matter. Such soils are a desirable medium for root growth because they have favorable moisture and nutrient characteristics and are well aerated. Therefore, the deeper the A horizon, the greater the volume of soil available for better root and top growth.

Considerably more soil volume than contained in the A horizon is required to supply water and nutrient requirements for trees. In southern Indiana the soils with deep A horizons usually have deep subsoils with desirable physical properties for rapid tree growth. On sites with shallow A horizons the subsoil is generally shallow and frequently stony, or it is high in clay content with low aeration porosity; consequently tree growth is slower.

[2] *Site index was calculated by setting tree age equal to 50 years, fixing variables at their mean sample value, and varying the factor of interest in each relationship.*

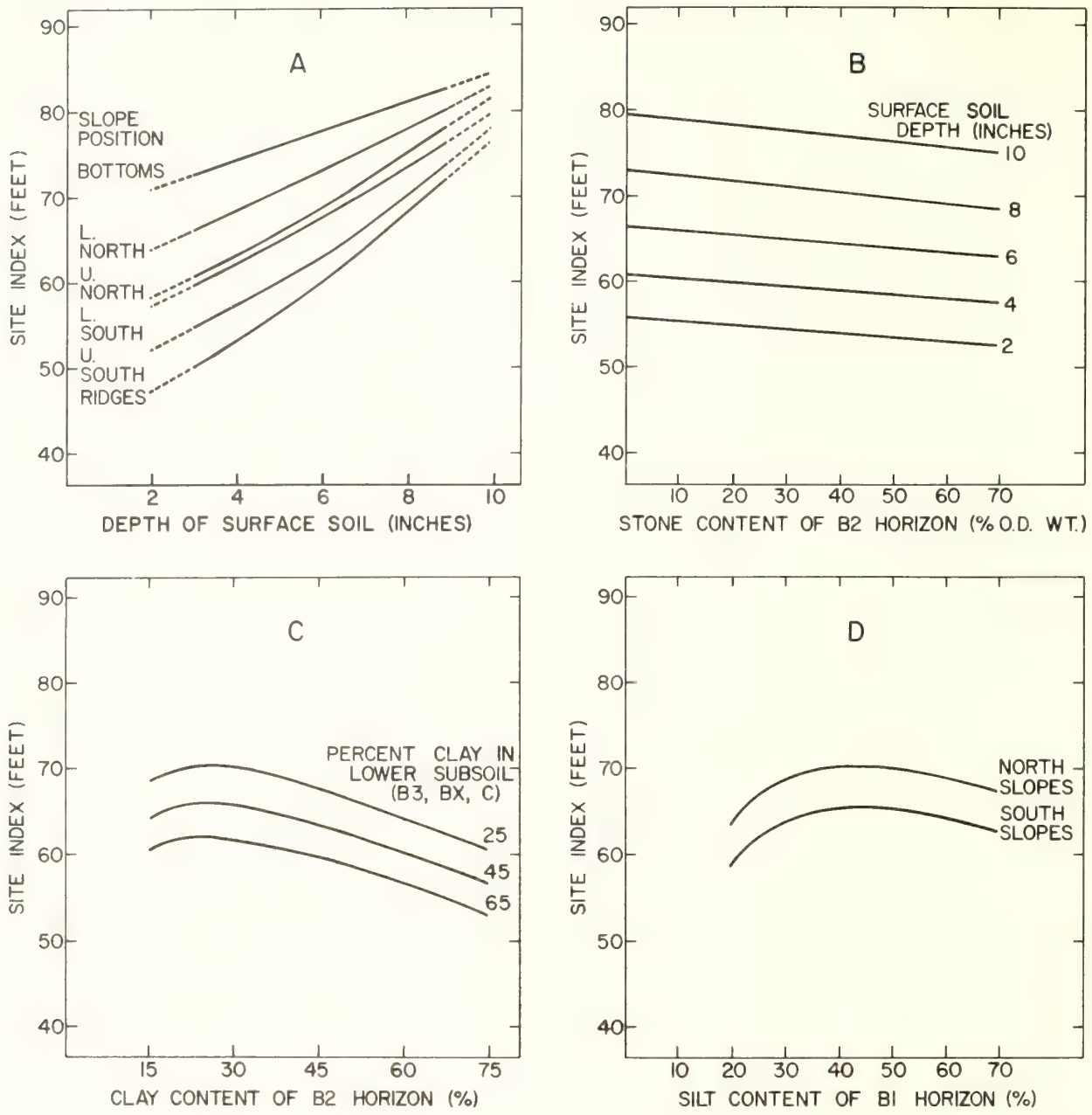

FIGURE 1. — Site index (feet — age 50 years) of white oak growing on Zanesville, Tilsit, Wellston, and Muskigum soils, as related to surface soil thickness (A1 + A2 horizons), slope position, stone content of B2 horizons, particle size fractions of subsoil horizons, and aspect.

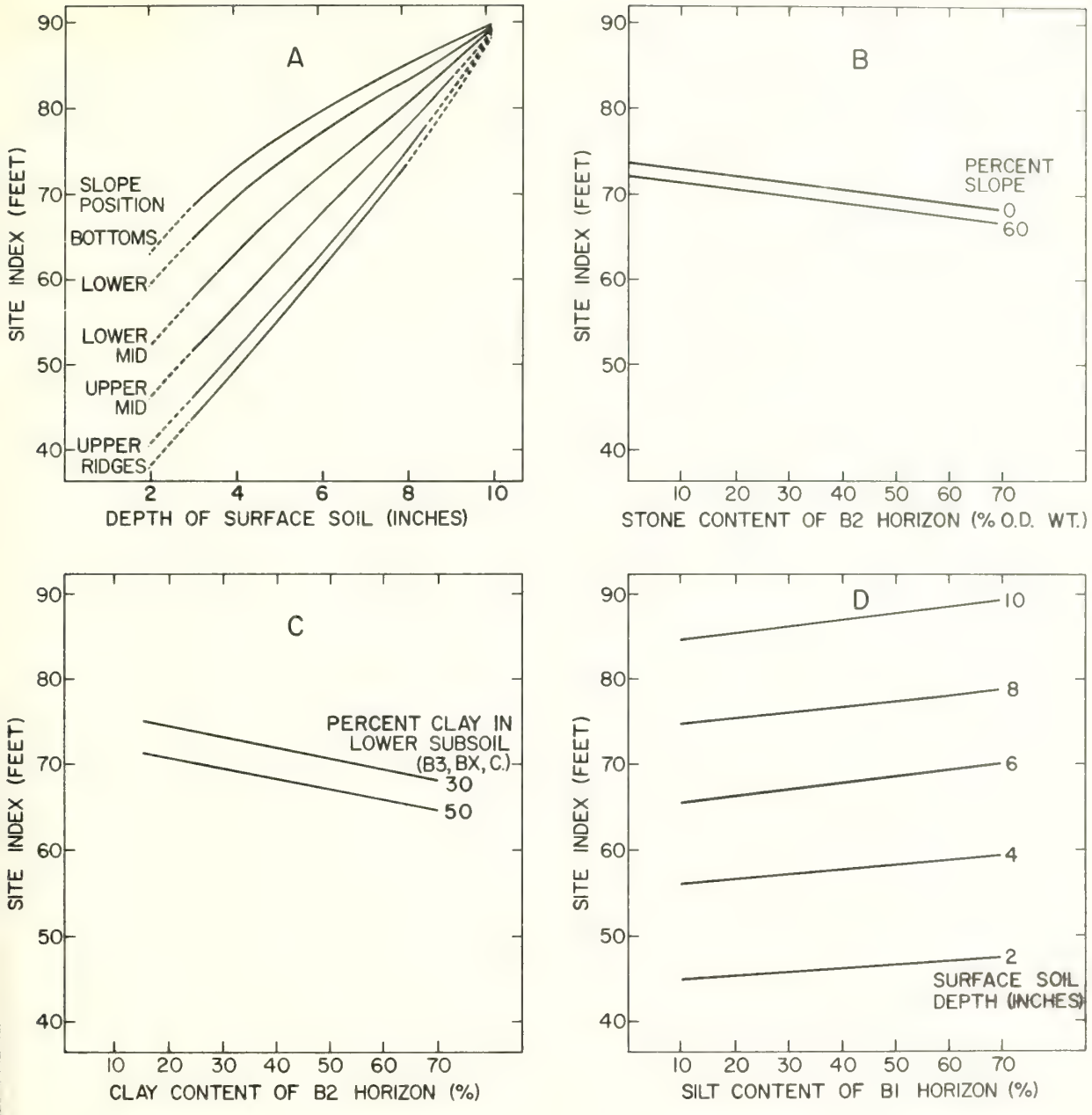

FIGURE 2. — Site index (feet — age 50 years) of black oak growing on Zanesville, Tilsit, Wellston, and Muskigum soils, as related to surface soil thickness (A1 + A2 horizons), slope position, stone content of B2 horizon, particle size fractions of subsoil horizons, and slope steepness.

Surface soil depth also is closely related to microclimate in the rough hilly country of southern Indiana. Deep A horizons occur on north-facing slopes, on lower slopes, and in coves where moisture and temperature are more favorable for tree growth. In contrast, thin A horizons generally occur on ridges and upper south-facing slopes where moisture is often limiting and temperatures are greater.

The good growth in areas of deep A horizons, then, is probably related both to favorable surface soil and subsoil properties and to favorable microclimate.

Clay Content In Subsoils

Site quality for white and black oak is best on sites with medium-textured subsoils (sandy clay loams, loams, and silt loams) and declines as soils become finer-textured (Figs. 1C and 2C). The site index trend for white oak is curvilinear, reaching a maximum at about 25 percent clay in the B2 horizon and then declining with increased clay content. Black oak shows a linear decrease in site quality as clay content in the B2 increased. Increasing clay content in the B3, BX (Fragipan), or C horizon results in a gradual decline in the site quality for both species (Figs. 1C, 2C).

These relationships suggest that soil moisture and soil aeration are near optimum for growth of white and black oak in the medium-textured subsoils. On sandier soil, aeration is good but less moisture is retained under the same precipitation pattern and so height growth of white oak is slower. On heavy-textured soils (clay loams, silty clay loams, silty clays, and clays), impeded aeration is apparently a detrimental factor and site quality for white and black oak gradually declines.

Silt Content of B1 Horizon

Site quality for black oak increases linearly as silt content of the B1 horizon increases (Fig. 2D). The trend for white oak is curvilinear, showing a sharp increase in site quality up to about 45 percent silt content and thereafter a gradual decline (Fig. 1D). These relationships suggest that with increasing silt content and proportionally less clay, improved aeration results in better growth of black oak. With white oak extremely high silt contents result in declining site quality, apparently because of reduced aeration in a uniformly fine, dense, and often poorly structured subsoil. These less favorable soil conditions for white oak usually occur in the thicker loess deposits of broad upland ridges.

Stone Content

Site quality for white and black oak decreases as stone content (material greater than 2 mm) of the subsoil increases (Figs. 1B, 2B). A similar trend was reported for black oak on medium-textured soils in Ohio (Carmean 1965). Probably the greater the volume of stone the less the volume of soil available for use by tree roots.

Slope Steepness, Position, and Aspect

Increasing slope steepness is not a significant factor in the site relations for white oak but results in a slight decrease in site quality for black oak (Fig. 2B). In southeastern Ohio, Carmean (1965) found that, for fine-textured soils located on broad, relatively flat ridges, site increased with increased slope steepness. He concluded that, under those conditions, an increase in slope steepness improved soil drainage and aeration and hence site quality. However, for medium-textured soils on steeper slopes Carmean (1968) obtained results similar to those of this study, namely, site decreases with increased slope steepness.

Site quality for both species improves with increasing distance from the ridge. This better growth is no doubt partially due to additions of gravitational water and to subsurface water flow from upper slope positions (Hewlett 1961) and to more favorable microclimatic conditions found on lower slopes.

White oak site quality in southern Indiana is decidedly better on north facing (NW, N, NE, E) slopes than on more southerly (SE, S, SW, W) aspects (Fig. 1D). However, aspect is not a significant factor in the site relations for black oak. The larger quantities of radiation received by south-facing

slopes (Geiger 1965) undoubtedly result in greater evapotranspiration which creates more severe moisture stresses within trees than occurs on less exposed north-facing slopes. Site quality is lower on south slopes than on north slopes because, ultimately, less moisture is available for tree growth. Work by Finney *et al.* (1962) in Ohio suggests that soil development is less favorable for tree growth on south slopes than on north slopes; northeast slopes had deeper litter and A1 horizons and more desirable chemical conditions than southwest slopes. These soil relations are undoubtedly largely due to differences in microclimate and soil moisture regimes associated with aspect and also with corresponding differences in floral and faunal composition.

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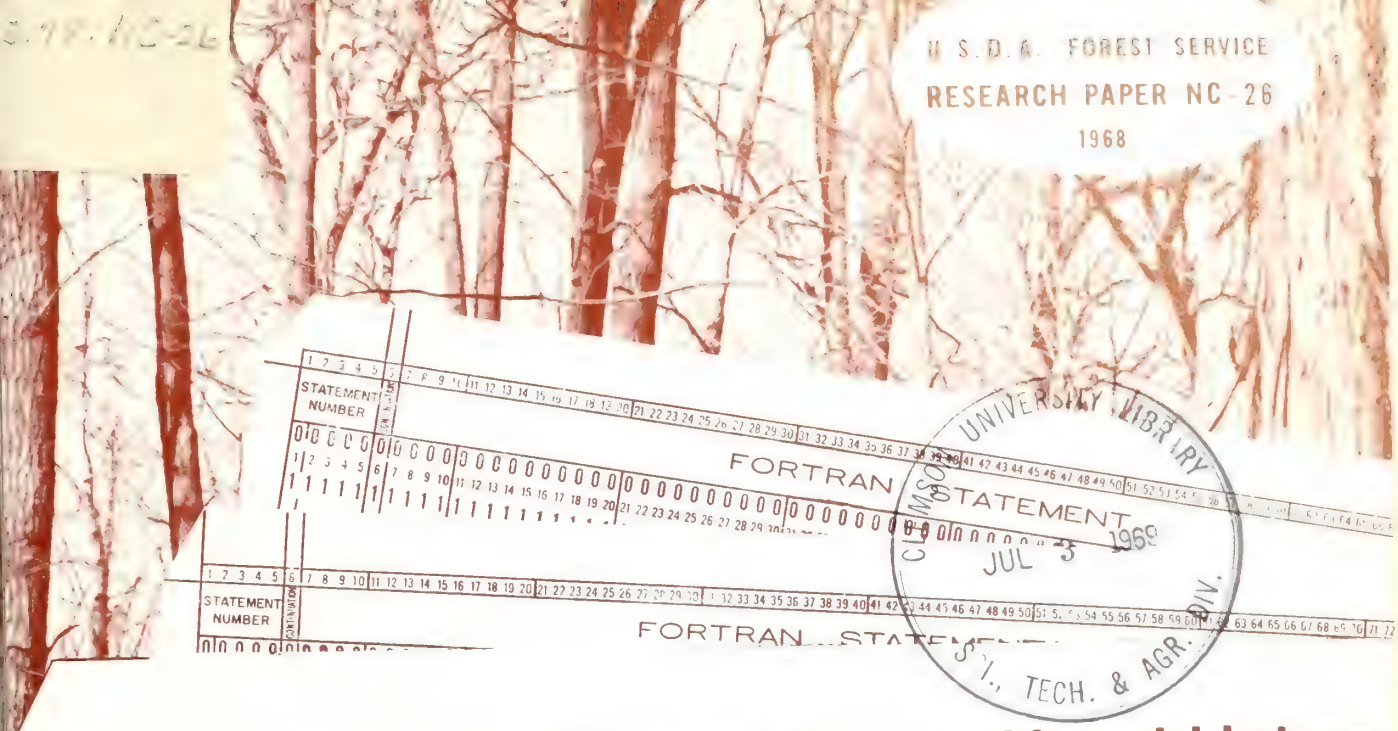

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a System for Classifying Wood-Using Industries and Recording Statistics for Automatic Data Processing

by E.W. Fobes, R.W. Rowe

NORTH CENTRAL FOREST EXPERIMENT STATION

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

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Foreword

Presented here is a method of recording wood industry statistics for automatic data processing — the result of a cooperative study by North Central Forest Experiment Station, Minnesota's Department of Iron Range Resources and Rehabilitation, and Department of Conservation Division of Lands and Forests.

Directories and other reports published by a number of eastern states were studied as well as methods used in gathering and compiling the data for them. The classification system and recording method developed as a result of this study (currently in use by Minnesota) is described in this report. Because specific needs vary between States, the method provides for items not currently used by Minnesota but which may be desirable elsewhere. It also provides for future expansion and inclusion of additional items.

Acknowledgement of advice and assistance in developing the method is due a number of individuals and organizations. Specific recognition is due Edwin Kallio, North Central Forest Experiment Station, U.S.D.A., Forest Service; Robert Peura, Minnesota Department of Conservation; John Brownell and William W. Barton of U.S.D.A., Forest Service, State & Private Forestry; Julian M. Opela, University of Minnesota at Duluth; and Ray Pfeifer, Michigan Department of Conservation.

A SYSTEM FOR CLASSIFYING WOOD-USING INDUSTRIES AND RECORDING STATISTICS FOR AUTOMATIC DATA PROCESSING

E. W. Fobes and R. W. Rowe

Detailed statistics about our wood-using industries are continually needed. One of the most common uses of such data is to locate buyers and sellers of wood products. The data are often compiled by various hand sorting methods into directories according to geographical location (counties, etc.), type of product (lumber, etc.), and type of operation (sawmills, treating plants, etc.). However, the usual hand sorting and compiling methods take so long that the directories may be out of date by the time they are published.

A pilot study was made in northern Minnesota by the State's Department of Iron Range Resources and Rehabilitation to evaluate the feasibility of using automatic data processing (ADP) to replace presently used hand methods of sorting and compiling wood industry statistics. Results indicate that success depends directly upon the industry classification system and method of recording and preparing field data for machine processing. Furthermore, it was determined that the system and method should be broad and flexible enough to include all items of current interest and additional data as needed. This report describes such a classification system and suggests a method of using it to prepare input data for ADP.

Items for which data are normally gathered were determined from recent surveys of wood-using industries made by various states. Questionnaires and recording forms, as well as items recorded, varied considerably. The most common recording system involved the use of edge-notched cards designed specifically for recording forest products industry data. Since there is a need for local as well as central office records, there would be advantages in using the edge-notched cards at the county level and ADP at the regional or state level. To facilitate transferring data from one system to the other, provision was made in the ADP system for all the items on the presently used edge-notched cards.

The original objective of the pilot study was to design a classification system for sawmills and a method of preparing input data for ADP that would facilitate compiling directory and production data. It soon became apparent that utilization and marketing specialists as well as researchers needed information on many more items. The objectives, therefore, were expanded to develop a system that:

1. Provides for data from all segments of the wood-using industry.

2. Can be easily revised and updated.

3. Provides for retention of data gathered and addition of data as they become available.

4. Permits sorting, regrouping, and analyzing all collected data.

5. Facilitates fast, accurate processing of input data.

6. Minimizes duplication and overlapping.

7. Provides an input medium that allows processing on any ADP equipment.

8. Permits development of standard reusable ADP programs for such projects as preparing directories and computing resource drain and other recurring reports.

A classification system and field recording method were developed to achieve these objectives.

Classification of Wood Products Processing Industries

The first step was to select terms that clearly define types of wood processing operations. A clear-cut classification system without duplication is highly desirable but difficult to design for wood-using firms. Overlapping and duplication can be minimized in most instances by using change in ownership or physical transfer of wood from one plant to another as criteria for classification. Therefore, five major divisions in the wood products industry were recognized: timber harvesting, primary wood processing, intermediate wood processing, end product processing, and end product using. These are described in detail below.

Timber Harvesting Industries

Includes all operations that remove trees or parts thereof from the forest. It includes felling trees, bucking into logs, skidding, and all other activities performed in the forest as well as transportation to processing plants, concentration yards, or other assembly points.

Primary Wood Processing Industries

Includes all plants that receive raw material directly from the forest, or in essentially the same form as produced by timber harvesting operations, and convert it to another product. These industries depend directly upon the forest. The total raw material purchased by these industries (excluding imports and exports) should equal the total produced by the timber harvesting industries. Subclassification of these industries is as follows:

Sawn Products Industry

Includes all plants that reduce round wood, as received from the forest, by sawing into marketable products: sawmills, stave mills, bolter mills, handle plants, tie and timber mills, shingle mills, etc. Sawmills that are adjunct to other operations would be excluded from this classification. Two examples are sawmills used by veneer mills to saw veneer cores into lumber and those used to saw cants for veneer slicers. In the first case the raw material for the sawmill is not in the form as received from the forest and in the second case the cants are not generally considered a marketable product.

Veneer Products Industry

Includes plants that convert logs, bolts, or cants into thin material by peeling, slicing, or sawing. It includes plants that produce both veneer and plywood, veneer and boxes, and veneer and baskets. It excludes plants that buy veneer for splicing or manufacturing plywood, boxes, baskets, and other items.

Fiber Products Industry

These are plants that produce such products as pulp, hardboard, insulation board, and roofing felt. Most of their raw material is in the form of pulpwood but some of it may be chips obtained directly from the woods or from other primary processing plants. Excluded are paper or other mills that purchase pulp from primary processing plants.

Other Industries Using Round Wood

Includes all processing plants that use raw wood produced by timber harvesting operations not included in the foregoing classes. Examples are post, pole, and piling plants; charcoal plants; specialty product plants; chemical distillation and extraction plants; excelsior plants; chipping plants; and particle board plants. Excluded are plants that treat sawn products.

Intermediate Wood Processing Industries

Plants in this classification receive their raw material from primary processing plants or other intermediate plants but do not process it into a final or end-use product. An example is a cut-up plant that receives lumber from sawmills and ships the cut-up parts to furniture plants. Another example is a veneer-splicing plant that receives veneer from veneer mills, splices and cuts it to size before shipping it to a kitchen cabinet door plant. Plywood plants producing furniture parts are included in this classification.

End-Product Processing Industries

Includes plants that receive raw materials from primary or intermediate processors and manufacture consumer products that require no further processing. Examples are furniture, toy, and sporting goods manufacturers; box, pallet, and crate manufacturers that purchase lumber; and paper mills that operate entirely on purchased pulp. Many primary processing plants retain ownership or control of the wood until it becomes an end-use product. These plants are not included in this category. Examples are softwood saw

mills producing planed lumber (an end product), veneer and plywood mills producing wall panels, hard board plants, and pulp and paper mills. Although these plants are classified as primary processing plants, the end products are also recorded. This permits including them in directories showing producers of specific products.

End-Product Using Industries

Includes wood-using industries not elsewhere recorded that provide markets for wood products. These may be wood-related industries such as lumberyards and building contractors, or totally unrelated industries such as machine manufacturers that purchase pallets, car blocking, etc.

The ADP Method

There appears to be a growing need for information on ADP, particularly the details for using it. Minnesota has used ADP directly to prepare and publish a directory of wood processors and users (see Appendix). Although other states have used ADP for compilation of data, few have prepared directories or other reports directly from machine printouts. Computer programs for doing this can be developed provided the input data are well organized.

Systematic recording of data for machine input is the first and one of the most important steps in the process. The edge-notched cards now widely used provide an organized system for recording data, but they cannot be used with the ADP equipment generally available. Punchcards, which serve the same purpose as edge-notched cards, can be used with such equipment. Another advantage of punchcards is that data punched can also be printed on the top edge of the card (fig. 1), making it possible to hand sort small quantities of cards that would be kept in county or other local offices. A disadvantage of hand sorting either edge-notched or punchcards is that they can become lost or mutilated. Duplicating punchcards, however, can be done rapidly by machine, while duplicating edge-notched cards is a slow, difficult process.

In the edge-notched card system presently being used, all the data for each company are recorded on one card. The amount of data that can be recorded for sorting is therefore limited to the number of holes in the edge of the card. Additional data must be recorded on, and read from, the face of the card. With the punchcard system, however, any number of cards can be used for each company, thereby greatly increasing the amount of data that can be machine sorted.

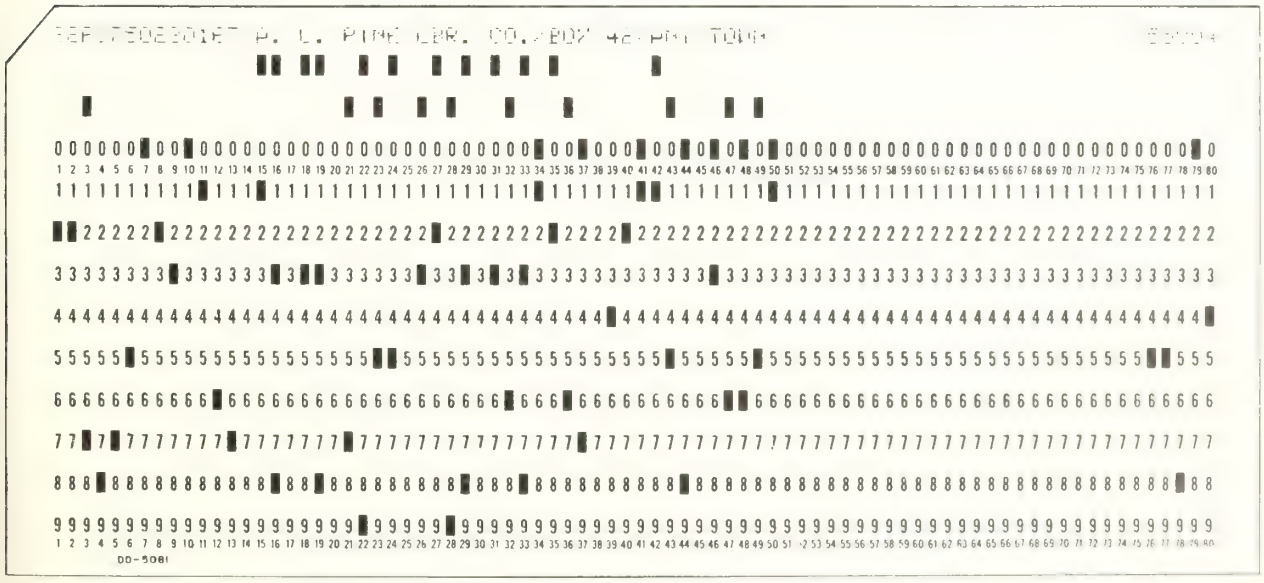

Figure 1. — Punchcard used in automatic data processing.

Field Recording Forms

A common procedure is to translate data recorded in the field to a coded form for punchcard operators. This step has been eliminated here by designing field forms that allow data to be recorded in code. Necessary coding instructions are included on the forms whenever possible.

Although the system described provides for recording data for the whole industry, just the timber harvesting and primary processing segments are illustrated in this report. Forms and coding instructions most frequently used for these two are included in the Appendix. As much as possible, forms were designed so they could also be used for other segments of the industry. Additional forms and card numbers are available for recording data not already included.

Those using the system will find it advantageous to extract the portion pertinent to their particular needs and prepare detailed instructions for field recording. Items not desired can be omitted when printing the recording forms but position of remaining items should not be changed.

Punchcard Numbering Scheme

The classifications for all wood-processing and wood-using industries have been described earlier in the report. The system provides 100 punchcards for recording data pertinent to these industries. Allocation of the cards for recording data to conform to the foregoing classifications is as follows:

Card	00	— Divisions within a State (Region, District, County, etc.)
"	01	— Company name, address, and zip code
Cards	02-07	— Telephone number; names of owner, manager, etc.
"	08	— Home of parent corporation
"	09	— Telephone number of parent corporation
"	10-19	— Timber harvesting operations
"	20-29	— Sawn products operations
"	30-39	— Veneer products operations
"	40-49	— Fiber products operations
"	50-59	— Other primary products operations
"	60-69	— Intermediate products operations
"	70-79	— End products operations
"	80-89	— End product users
"	90-99	— Special study data not recorded or obtainable from the preceding cards, data that are confidential or undesirable for permanent recording. These cards are not to be a part of the permanent file.

In general the first card under each classification has information that seldom changes. Card 01, for example, has the company name, which changes less frequently than the personnel recorded on card 02. (Card 01 can be used for printing address labels for monthly newsletters or other reports.) Cards 10, 20, 30, etc., are used to record data on equipment, which will change less frequently than such data as production and number of employees recorded on subsequent cards. The 10 card numbers allocated to each major classification allow for recording a large amount of data, and should adequately provide for future expansion.

Punchcard Coding

Numbers are used wherever possible on punchcards instead of letters because letters require twice as much time to machine sort. In printing directories or reports the computer is programmed to print out words that numbers represent. An alphameric number (one using both letters and numbers) is used for the company identification number to permit alphabetical sorting. The first 13 columns on each card are reserved for identification information:

Columns	1- 2	— State Code Number
"	3- 7	— Alphameric numbers used for identification and alphabetical sorting
"	8- 9	— Industry classification Code Number
"	10-11	— Card number
"	12-13	— Year data on the card is pertinent

The remaining columns are for recording other data.

Identification code is the same as that given in the recording form instructions in the Appendix.

Summary

Recording and compiling information for directories and other reports of the wood-using industry can be accomplished by automatic data processing. Economic and other advantages derived depend upon the system of recording the collected data for machine processing. Punchcards are a practical medium to use for this purpose. A system for dividing the industry into classes and allocating cards to each class has been devised. Recording forms are also described for this suggested system, from which collected data are punched directly into cards. Sample forms are included in the Appendix.

Appendix

Recording Forms

Forms and coding instructions for recording data pertaining to harvesting and primary processing plants are included in this section. Wherever possible, they were designed so they would be applicable elsewhere in the system. Form 12, for example, can be used for recording data on logs produced on harvesting operation or for logs used by a primary processing plant. The included forms provide space for currently pertinent data and will serve as a guide to preparation of additional forms when needed.

Provision is made for a considerable amount of data; as much or as little as needed can be recorded. Instructions can be issued accordingly to disregard the undesired items and designate the forms or data to be recorded. An alternative is to delete the unwanted items and coding instructions when printing forms. If this is done, it is important to leave the remaining items in their originally assigned places.

Instructions to recorders should include the following:

Put only one number or symbol in each blank square.

Use 0 to designate none instead of leaving the space blank; a blank indicates data are lacking or unknown.

Where a percentage is required and only one or two spaces are provided, enter a hyphen in each space to indicate 100 percent. (This will then be punched in the 11 or X position on the card.) When actual volume figures are obtained in the field, they can be written on the form and percentages can be computed and entered in the office.

The box in the upper right-hand corner of each form is to be used by field recorders who will use the same number for all forms pertaining to the same mill, operation, or plant. This is for temporary identification in case sheets for a given company should become detached or separated before permanent mill numbers are assigned to blocks 3 through 7. Permanent numbers will be assigned according to an alphabetical listing prepared in the State office.

State code number (blocks 1 & 2). — To be entered according to the following: Connecticut 06, Delaware 07, Illinois 12, Indiana 13, Iowa 14, Maine 18, Maryland 19, Massachusetts 20, Michigan 21, Minnesota 22, Missouri 24, New Hampshire 28, New Jersey 29, New York 31, Ohio 34, Pennsylvania 37, Rhode Island 38, Vermont 44, West Virginia 47, Wisconsin 48. (Reference Geographical Location Codes GSA.)

Identification code. — An identification code consisting of the first letter of the company name or individual's surname and numerals will be used for identification. This same number will also be used to prepare alphabetical listings. The appropriate letter will be entered in column 3. Numbers will be entered in columns 4 through 7 in the State office. In the initial listing the first 3 columns following the letter will be used thus leaving the 4th column (no. 7) for later additions.

Type of industry code numbers (blocks 8 & 9). — To be entered according to the industry classification as follows:

10 — Harvesting
20 — Sawn products industry
30 — Veneer industry
40 — Fiber products industry
50 — Other industries using round wood
60 — Intermediate processing industries
70 — End products producers
80 — End users of wood products

Detailed subclasses for each of the above are shown on form 01. The major industry classification code should be used when the industry does not conform to any of the subclasses.

Form Number 00

Title Location

To be used for Card Number 00

Temporary Number

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers	
6		to be entered	
7		in State Office	
8		Industry Code	
9		Classification	
10	0	Card	
1	0	Number	
2		Year data are	
3		Pertinent	
4		County	
5		Code	
6		Number	
7		Region within the state	
8			
9		Area designation	
20		within the state	
1		District within	
2		the area or region	
3		Space	
4		Ownership - Code *	
5		Forest-Survey Unit	
6			
7			
8			
9			
30			
1			
2			
3			
4			
5			
6			
7			
8			
9			
40			

This form to be filled out in the office. Punch cards to be used for sorting by areas.

Instructions

#24 Ownership - Code
1. Independent.
2. One of several owned by same company.
3. Department
4. Subsidiary
9. Other

Name and address of parent company to be recorded on Form 01 and punched on Card 08. Telephone No. and key personnel to be recorded on Form 02 and punched on Card 09.

Column Number	
1	
2	
3	
4	
5	
6	
7	
8	
9	
50	
1	
2	
3	
4	
5	
6	
7	
8	
9	
60	
1	
2	
3	
4	
5	
6	
7	
8	
9	
70	
1	
2	
3	
4	
5	
6	
7	
8	
9	
80	

* See Instructions for Code

Form Number 01

Title Name & Address

To be used for Card Number

Temporary Number

Column Number			
1		State Code Number	
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification*	
9			
10	0	Card Number	
11	1		
2		Year data are Pertinent	
3			
4			
5			

IDENTIFICATION CODES

Enter CAPITAL letters, commas, periods, spaces, and numbers as in typing. Abbreviate where necessary and customary; e.g., LBR., CO., etc. Enter continuously with a / after name, address, and town; e.g. PINE LBR. CO., INC./BOX 93/ OAKVILLE/ Since company names, address, etc., vary in length it is necessary to use the / between items to indicate the end of the item so the processing equipment can be instructed to print the following item on the next line or whatever other instructions are appropriate.

* INDUSTRY CODES CLASSIFICATION
Classify According to Major Activity

Column Number		
5		
	C	10 HARVESTING NEC. (Not Elsewhere Classified)
	O	11 Pulpwood.
	M	12 Logs; saw and/or veneer.
8		13 Pulpwood and logs.
9	P	14 Posts, poles and/or piling.
		15 Bolts; handle, stave, excelsior, etc.
	A	16 Wood; fuel, charcoal, chemical, etc.
		17 Christmas trees.
20		18 Maple syrup or resin.
1	N	19
2	Y	20 SAWN PRODUCTS INDUSTRY NEC.
3		21 Softwood lumber.
		22 Hardwood lumber.
	N	23 Both softwood & hardwood lumber.
4		24 Ties and timbers.
5	A	25 Laths, slats, shingles, etc.
		26 Core stock lumber.
6	M	27 Sawn and intermediate products.
		28 Sawn and finished products. (e.g. lumber and pallets).
7	E	29 Blocking & crating.
8	/	30 VENEER INDUSTRY NEC.
9		31 Face veneer for wall panels, doors, etc.
	A	32 Face veneer for furniture, cabinets, etc.
		33 Non-face veneer for cross banding, core, furniture, etc.
1	D	34 Container veneer for boxes, etc.
2	D	35 Specialty veneer for tongue depressors, matches, etc.
		36 Veneer and plywood for panels.
3	R	37 Veneer and plywood for furniture.
4	E	38 Veneer and plywood for containers, construction, etc.
5	S	39 Veneer and plywood for specialty products.
6	S	40 FIBER PRODUCTS INDUSTRY NEC.
7	/	41 Pulp.
		42 Pulp and paper.
8		43 Pulp and hardboard.
		44 Pulp and insulation board.
9		45 Pulp and roofing felt.
		46 Pulp and moulded products.
40		47 Pulp and food containers.
		48
		49

Column Number		
1	T	50 OTHER INDUSTRIES USING ROUND WOOD NEC.
2	O	51 Charcoal.
		52 Particle board, flake board, etc.
3	W	53 Shavings and bedding.
4	N	54 Rustic fencing and furniture.
		55 Excelsior.
		56 Posts.
5		57 Chips for fiber products.
		58 Poles and piling.
6	O	59
7	R	60 INTERMEDIATE INDUSTRIES NEC.
8		61 Cut stock for furniture, cabinets, etc.
		62 Shook for containers, pallets, etc.
9	C	63 Blanks for gun stock, sporting goods, etc.
		64 Turning squares.
50	I	65 Dried lumber (kilns and concentration yards).
		66 Millwork products, moulding, etc.
1	T	67 Veneer products, spliced veneer faces, etc.
		68 Plywood products, door skins, etc.
2	Y	69 Particle board and related products.
3	/	70 END PRODUCTS PRODUCERS NEC.
4		71 Furniture, caskets, store fixtures, cabinets, and similar manufactured products.
5		72 Packaging and handling products--boxes, crates, pallets, excelsior, barrels, wire reels, etc.
6		73 Recreation and related products--sporting goods, toys, novelties, boats, etc.
7		74 Turned and shaped products--(other than sporting goods) spools, bobbins, handles, etc.
8		75 Building and construction products--finished lumber, doors, mouldings, etc.
9		76 Treated wood products--poles, posts, ties, etc.
60		77 Paper, other fiber products and wood particle products (not solid wood).
1		78 Plywood and laminated products--wall panels, etc.
2		79 Wood by-products and derivatives--wood flour, bark products, gums, resins, charcoal, etc.
3		80 END USERS OF WOOD PRODUCTS NEC.
4		81 Related wood using industries. NEC.
5		82 Lumber yards, wholesalers, etc.
6		83 Home building industry--manufacturers of mobile, or prefabricated homes, building contractors, etc.
7		84 Paper, printing, fiber and related industries.
8		85 Unrelated industries. NEC.
9		86 Food processing and agricultural industries.
70		87 Transportation industry--railroads, manufacturers of trailers, truck bodies, etc.
1		88 Hard goods industry--manufacturers of appliances, machines, autos, tools, etc.
2		89 Soft goods industry--manufacturers of textiles, wearing apparel.
3		
4		
5		
6		Z I P
7		C O D E
8		
9		
80		

Form Number 02

Title Telephone & Personnel

To be used for Card Number 02 and 09

Temporary Number

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10	0	Card Number	
1	2		
2		Year data are Pertinent	
3			
4		Area No.	Telephone Number
5			
6			
7	X		
8		Exchange No.	
9			
20			
1	X		
2			
3			
4			
5			
6		Individuals Name and Title	
7			
8			
9			
30			
1			
2			
3			
4			
5			
6			
7			
8			
9			
40			

Enter name of Owner, President, manager or other key individual. Abbreviate title and enter periods, commas, and spaces as needed.

Example: JOHN P. SMITH, OWR./L. W. JONES, PRES./

Enter / at end of each item.

Column Number	
1	
2	
3	
4	
5	
6	
7	
8	
9	
50	
1	
2	
3	
4	
5	
6	
7	
8	
9	
60	
1	
2	
3	
4	
5	
6	
7	
8	
9	
70	
1	
2	
3	
4	
5	
6	
7	
8	
9	
80	

Form Number 10

Title Equipment

Includes harvesting, sawn products and roundwood producers.

To be used for Card Number 10, 20, 50

Column Number			
1		**State Code Number**	IDENTIFICATION CODES
2			
3		**First Letter of** Co. or Family Name	
4			
5		**Code Numbers to be entered in State Office**	
6			
7			
8		**Industry Code Classification**	
9			
10		**Card Number**	
1			
2		**Year data** are	
3		**Pertinent**	
4		Space	
5		Chain saws	NUMBER OF PIECES OF EQUIPMENT
6			
7		"Timber Harvesters"	
8		Horses & Mules	
9		Crawler Tractors	
20		Wheel Tractors	
1		Arches	
2		Wheel Skidders	
3		skidding Trailers	
4		"Pre Haulers"	
5		Self Loading Crawlers	
6		Cranes & Jammers	
7		Shovel Loaders & Heel Booms	
8		Forklifts & Front End Loaders**	
9		Trucks	
30		Self-Loading Trucks	
1		Tractor Trucks (Semi)	
2		Trailers (Semi)	
3		Towboats	
4		Portable Mechanical Peelers	
5		Mobile Mechanical Chippers	
6		Stationary Peelers	
7		Stationary Chippers and Shredders	
8		Chip Screen Installations	
9		Space	
40		Headsaw - Code*	

Instructions

#40 Headsaw Code
1. Circular
2. Band
3. Sash Gang
4. Twin Circular
5. Multiple Circular
6. Multiple Band
7. Bolter
8. Mobile Circular
9. Other

#41 Carriage Code
1. Sawyer Hand Set
2. Rider on Carriage
3. Riderless Hydraulic Set
4. Riderless Electric Set
5. Riderless Air Set
6-8 Space
9. Other

#42 Edger Code
1. Single Arbor
2. Double Arbor
3-8 Space
9. Other

#43 Dry Kiln Capacity Code
1. 1 - 25 MBF
2. 26 - 50 MBF
3. 51 - 100 MBF
4. 101 - 200 MBF
5. 201 - 500 MBF
6. 501 MBF & over

Temporary Number

Column Number			
1		*Carriage - Code	
2		*Edger - Code	
3		*Dry Kiln(s) - Code by capacity	
4		Space	
5		Resaws Incl. Line Bar Type	NUMBER OF PIECES OF EQUIPMENT
6		Trimmer Saws (end trim)	
7		Grading Chains	
8		Hogs, Hammermills, etc.	
9		Burners	
50		Automatic Stackers	
1		Planers, Surfacers, Jointers	
2		Moulders & Matchers	
3		Post Pointers	
4		Rip Saws	
5		Space	
6		Vats (treating)	
7		Pressure Treating Cylinders	
8		Space	
9		Forklifts (inside plant)	
60		Straddle Trucks	
1		Shavings Machines (for bedding, etc.)	
2		Dryers (shavings, chips, sawdust)	
3		Space	
4		Garland Machines (Xmas decorations)	
5		Maple Syrup Cookers	
6		Charcoal Kilns	
7		Charcoal Briquetting Machines	
8		Lath Weavers	
9		Lath Strippers	
70		Space	
1		Other Eqpmt. for Processing Solid Wood	
2		Other Eqpmt. for Processing Veneer Plywd.	
3		Other Eqpmt. for Processing Chips	
4		Other Eqpmt. NEC	
5			
6			
7			
8			
9			
80			

* See Instructions for Code
** Used outside the plant

Form Number 11

Title Harvesting

To be used for Card Number 11

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers	
6		to be entered	
7		in State Office	
8		Industry Code	
9		Classification	
10	1	Card	
1	1	Number	
2		Year data are	
3		Pertinent	
4		Space	
5		Type of Operation - Code*	
6		Transportation to Market-Rank 1 Code *	
7		Transportation to Market-Rank 2 Code *	
8		Space	
9		Estimated Value of	
20		Equipment to	
1		nearest $M	
2		Space	
3		General Condition of Felling Eqpmt. *	
4		General Condition of Felling Eqpmt. *	
5		General Condition of Loading Eqpmt. *	
6		General Condition of Hauling Eqpmt. *	
7		Space	
8		Average Number of Men	
9		Felling and Bucking	
30		Average Number of Men	
1		Skidding	
2		Average Number of Men	
3		Bucking & Loading at Landing	
4		Average Number of Men	
5		Hauling	
6		Average Number of Men	
7		Employed in Harvesting Operation	
8		Maximum Number of Men	
9		Employed	
40		(Peak Season)	

* See instructions for code

Instructions

#15 Type of Operation
1. Logs
2. Pulp
3. Tree length logs
4. Tree length pulp
5. Posts, poles, piling
6. Logs & pulp
7. Tree length logs & pulp
8. Xmas trees
9. Other

#16&17 Transportation to Market - Code
1. Truck
2. Rail
3. Water
4-8 Space
9. Other

#23-26 General Condition of Eqpmt.
1. New
2. Good
3. Fair
4. Poor

Column Number		
1		Space
2		Number of Weeks
3		Worked in Year
4		Normalcy of Work Year - Code *
5		Space
6		Average Daily Wage of
7		Piece Worker to nearest dollar
8		Average Daily Wage of
9		Hourly Employee to nearest dollar
50		
1		
2		
3		
4		
5		
6		
7		
8		
9		
60		
1		
2		
3		
4		
5		
6		
7		
8		
9		
70		
1		
2		
3		
4		
5		
6		
7		
8		
9		
80		

Temporary Number

#44 Normalcy of Work Year (in time worked)
1. Below normal
2. Normal
3. Above normal

Form Number 12

Title Logs Produced or Used

To be used for Card Number 12

Temporary Number

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10		Card Number	
1			
2		Year data are Pertinent	
3			
4		Space	
5		Size Class - Code *	
6		Actual Annual Production or Consumption All Species (Logs)	
7			
8			
9			
20			
1		Unit of Measurement - Code *	
2		Utilization - Code *	
3		Softwood % of Total Produced or Used	
4			
5		B-Fir	% OF SOFTWOOD
6			
7		Cedar, White or Red	
8			
9		Hemlock	
30			
1		Pine, Jack	
2			
3		Pine, Red	
4			
5		Pine, White	
6			
7		Spruce or Cypress	
8			
9		Tamarack or So. Pine	
40			

* See Instructions for Code

Instructions

#15 Size Class - Code

0. Idle
1. 1 - 49
2. 50 - 99
3. 100 - 249
4. 250 - 499
5. 500 - 999
6. 1,000 - 1,999
7. 2,000 - 4,999
8. 5,000 - 9,999
9. 10,000 & over

#21 Unit of Measurement - Code

1. MBF
2. Cord
3. Tons
4. M cubic feet
5. Pieces
6. Lineal feet
7. M square feet
8. Space
9. Other

#22 Utilization - Code

1. Produced
2. Consumed
3. Purchased

Column Number			
1		Hardwood % of Total Produced or Used	
2			
3		Ash	% OF HARDWOOD
4			
5		Aspen	
6			
7		Basswood	
8			
9		Beech	
50			
1		Birch	
2			
3		Cherry	
4			
5		Cottonwood	
6			
7		Elm	
8			
9		Hickory	
60			
1		Maple, Hard	
2			
3		Maple, Soft	
4			
5		Oak, Red	
6			
7		Oak, White	
8			
9		Walnut, Black	
70			
1		Poplar, Tulip	
2			
3		Sycamore	
4			
5		Gum	
6			
7		Other	
8			
9			
80			

Form Number 13

Title Cordwood Produced or Used

To be used for Card Number 13-42-52

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10		Card Number	
1			
2		Year data are Pertinent	
3			
4		Space	
5		Size Class - Code *	
6		Actual Annual Production or Consumption All Species (cordwood)	
7			
8			
9			
20			
1			
2			
3		Unit of Measurement - Code *	
4		Utilization - Code	
5		Softwood % of Total Produced or Used	
6			
7		B-Fir	% OF SOFTWOOD
8			
9		Hemlock	
30			
1		Pine, Jack	
2			
3		Pine, Red	
4			
5		Pine, White	
6			
7		Spruce, Black	
8			
9		Spruce, White	
40			

*See Instructions for Code

Instructions

#15 Size Class - Code
0. Idle
1. 1 - 49
2. 50 - 99
3. 100 - 249
4. 250 - 499
5. 500 - 999
6. 1,000 - 1,999
7. 2,000 - 4,999
8. 5,000 - 9,999
9. 10,000 & over

#23 Unit of Measurement - Code
1. MBF
2. Cord
3. Tons
4. M cubic feet
5. Pieces
6. Lineal feet
7. M square feet
8. Space
9. Other

#24 Utilization - Code
1. Produced
2. Consumed
3. Purchased

Column Number			
1		Tamarack or So. Pine	% OF HARDWOOD
2			
3		Hardwood % of Total Produced or Used	
4			
5		Ash	
6			
7		Aspen	
8			
9		Beech	
50			
1		Birch	
2			
3		Cherry	
4			
5		Cottonwood	
6			
7		Elm	
8			
9		Maple, Hard	
50			
1		Maple, Soft	
2			
3		Oak, Red	
4			
5		Oak, White	
6			
7		Sycamore	
8			
9		Gum	
70			
1		Mixed Hardwood	
2			
3		Other Hardwoods NEC	
4			
5		Total Hardwood in Logs	% to nearest 10%
6		Total Softwood in Logs	
7		Softwood Pulp Peeled	
8		Hardwood Pulp Peeled	
9		Softwood as Chips*	
80		Hardwood as Chips*	

Temporary Number

#79 - 80 Produced or Used Chips - This means chips by producer or purchased chips

Form Number 14

Title Pole & Piling Production and Consumption

To be used for Card Number 14 & 52

Temporary Number

Column Number		
1		State Code Number
2		
3		First Letter of Co. or Family Name
4		
5		Code Numbers to be entered in State Office
6		
7		
8		Industry Code Classification
9		
10		Card Number
1		
2		Year data are Pertinent
3		
4		Space
5		Annual Size Class - Code *
6		Actual Annual Production or Consumption All Species (Piling)
7		
8		
9		
20		
1		Unit Of Measurement - Code *
2		Utilization - Code *
3		Pine, Jack
4		
5		Pine, Red
6		
7		Pine, White
8		
9		Western
30		
1		Southern
2		
3		Other
4		
5		Space
6		
7		
8		
9		
40		Annual Size Class - Code *

IDENTIFICATION CODES

% OF PILING PRODUCTION OR CONSUMPTION

*See Instructions for Code

Instructions

#15-40-66 Annual Size Class - Code

0. Idle
1. 1 - 49
2. 50 - 99
3. 100 - 249
4. 250 - 499
5. 500 - 999
6. 1,000 - 1,999
7. 2,000 - 4,999
8. 5,000 - 9,999
9. 10,000 & over

#21-46-73 Unit of Measurement - Code

1. MBF
2. Cords
3. Tons
4. M cubic feet
5. Pieces
6. Lineal feet
7. M square feet
8. Space
9. Other

#22-47-74 Utilization - Code

1. Produced
2. Consumed
3. Purchased

Column Number		
1		
2		Actual Annual Production or Consumption All Species (Poles)
3		
4		
5		
6		Unit of Measurement - Code *
7		Utilization - Code *
8		Cedar
9		
50		Pine, Jack
1		
2		Pine, Red
3		
4		Pine, White
5		
6		Spruce
7		
8		Tamarack
9		
60		Western
1		
2		Southern
3		
4		Other
5		
6		Annual Size Class - Code *
7		Posts, all species produced or consumed
8		
9		
70		
1		
2		
3		Unit - Code *
4		Utilization - Code *
5		Cedar
6		Other Softwood
7		Oak
8		Other Hardwood
9		
80		

PERCENT OF PRODUCTION CONSUMPTION

To nearest 10%

Form Number 15

Title _____

To be used for Card Number 15

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers	
6		to be entered	
7		in State Office	
8		Industry Code	
9		Classification	
10	1	Card	
15	5	Number	
2		Year data are	
3		Pertinent	
4		Space	
5		Status - 1. Idle 2. Active	
		% Logs Produced Used in Own Mill *	
		% Logs Produced and sold Locally *	
8		Other Log Outlets, %, specify *	
		% Pulp Production Sold on Open Market *	
20		% Pulp Production Sold on Contract *	
1		Space	
2		Distance to	
3		Main Market	
4		In Miles	
5		Own Lands	Source of timber to nearest 10% (1=10%)
6		Farm Wood lot or Small Private	
7		Absentee Owner	
8		Industrial	
9		County	
30		State	
1		Federal	
2		Space	
3		Do you Sell Logs on Grades 1. Yes 2. No	
4		Vener Logs,	PRODUCED
5		Nearest 1%	
6		Sawlogs,	
7		Nearest 1%	
8		Tie Cuts,	
9		Nearest 1%	
40		Space	

* See Instructions for Code

Instructions

#16-18 Disposal of Logs

To Nearest 10% & covers all log production

#19-20 Disposal of Pulp

Nearest 10% & Covers all pulp production; contract made before wood cut (#20).

Column Number			
1		Other Sawlog Products, Nearest 1%	
2			
3		Space	
4		Pulp Sale Method(s) *	
5		% of Pulp Sold	
6		by Weight	
7		Space	
8			
9		Xmas Trees	
50			
1		# of Trees Produced	
2			
3			
4			
5			
6		B-fir	Total Xmas Tree Production - to nearest 10%
7		Spruce	
8		Scotch Pine	
9		Red Pine	
60		White Pine	
1		Other	
2		B-fir	Plantation Produced Xmas Trees to nearest 10%
3		Spruce	
4		Scotch Pine	
5		Red Pine	
6		White Pine	
7		Other	
8		B-fir	Sheared Xmas Trees Produced to nearest 10%
9		Spruce	
70		Scotch Pine	
1		Red Pine	
2		White Pine	
3		Other	
4		Do you produce boughs? 1. No 2. Yes	
5			
6			
7			
8			
9			
80			

Temporary Number

#44 Pulp Sale Method(s)
1. Scale
2. Weight
3. Scale & Weight

Form Number 21

Title Sawmill

To be used for Card Number 21

	State Code Number	IDENTIFICATION CODES	
	First Letter of Co. or Family Name		
	Code Numbers to be entered in State Office		
	Industry Code Classification		
2	Card		
1	Number		
	Year data are Pertinent		
	Space		
	Mill Power - Code *		
	Mill Mobility - Code *		
	Space		
	Rated Daily Capacity - MBF *		
	Potential Annual Capacity - Code *		
	Space		
	Number of Men Barking and Chipping		
	Number of Men on Mill Floor		
	Total Number of Men Employed at this Operation		
	Space		
	Replacement Value - Code *		
	Estimated Value - Code *		
	Space		
	Basic Products - Code, Rank 1 *		
	Basic Products - Code, Rank 2 *		
	Basic Products - Code, Rank 3 *		
	Space		
	Seasoning of Products - Code, Rank 1 *		
	Seasoning of Products - Code, Rank 2 *		
	Seasoning of Products - Code, Rank 3 *		
	Grading of Product - Code*		
	Grading - Code *		

*See Instructions for Code

Instructions

#15 Mill Power - Code
1. Gasoline 4. Steam
2. Diesel 5-8 Space
3. Electric 9. Other

#16 Mill Mobility - Code
1. Stationary
2. Semi-stationary
3. On wheels
4-8 Space
9. Other

#18&19 Rated Daily Capacity - MBF sawed in one 8-hour period with full crew, no breakdowns and average logs.

#20 Potential Annual Capacity Code (250 days X Rated Daily Capacity)
0. Idle
1. 1-49 MBF
2. 50 - 99 MBF
3. 100 - 249 MBF
4. 250 - 499 MBF
5. 500 - 999 MBF
6. 1,000 - 1,999 MBF
7. 2,000 - 4,999 MBF
8. 5,000 - 9,999 MBF
9. 10,000 MBF & over

#29 Replacement Value Code (do not include real estate)
1. $1 - $4,999
2. $5,000 - 9,999
3. $10,000 - 24,999
4. $25,000 - 49,999
5. $50,000 - 99,999
6. $100,000 - 249,999
7. $250,000 - 499,999
8. $500,000 - 1 Million
9. Over $1 Million

#30 Estimated Value - Code
Do you (field man) feel equipment appraisal is
1. Realistic 3. Too Low
2. Too High

#32-34 Basic Products -Code, Rank 1, 2, 3
Rank 1 means the most important;
Rank 2 means the second most important, etc.
1. Lumber
2. Lath
3. Shingles
4. Studs
5. Ties, Timbers & Cants
6. Shavings
7. Charcoal
8. Chips
9. Other

Column Number		
1		Planing of Product - Code *
2		Treating of Prod. - Code, Rank 1 *
3		Treating of Prod. - Code, Rank 2 *
4		Space
5		Slab & Edging Use - Code, Rank 1 *
6		Slab & Edging Use - Rank 1 to nearest 10%
7		Slab & Edging Use - Code, Rank 2 *
8		Slab & Edging Use - Rank 2 to nearest 10%
9		Space
50		Sawdust Use - Code, Rank 1 *
1		Sawdust Use, Rank 1 to nearest 10%
2		Sawdust Use - Code, Rank 2 *
3		Sawdust Use - Rank 2 to nearest 10%
4		Space
5		Bark Use - Code, Rank 1 *
6		Bark Use, Rank 1 to nearest 10%
7		Bark Use - Code, Rank 2
8		Bark Use, Rank 2 to nearest 10%
9		Space
60		Logs Purchased
1		to nearest %
2		Logs Cut on own Operation to nearest %
3		
4		Logs Custom Sawed
5		to nearest %
6		Space
7		Timberland ownership (1=Yes, 0=No) *
8		
9		
70		
1		
2		
3		
4		
5		
6		
7		
8		
9		
80		

Temporary Number

#36-38 Seasoning of Products - Code Rank 1, 2, 3
1. Kiln Dry 3. Air Dry
2. Forced Air Dry 4. Green

#39 Grading of Products - Code
1. Does not grade
2. Partially grades
3. Grades to "Assn. Standards"
9. Other

#40 Grading - Code
1. Grades only softwood
2. Grades only hardwood
3. Grades both
9. Other

#41 Planing of Product
1. Does not plane
2. Planes softwood only
3. Planes hardwood only
4. Planes both
9. Other

#42 Treating of Product - Code, Rank 1
1. Salt treatment
2. Anti stain 4. Penta
3. Creosote 9. Other

#43 Treating of Product - Code, Rank 2

#45-48 Slab & Edging Use - Code
1. Burn as waste
2. Burn as fuel
3. Sell for fuel
4. Sell for chipping
5. Sell for charcoal
6. Chips for pulp
7. Chip for agriculture
8. Use for fill
9. Other

#50-53 Sawdust Use - Code
1. Burn as waste
2. Burn as fuel 6. Use for fill
3. Sell for fuel 7-8 Space
4. Give away 9. Other
5. Sell for agric. use

#55-58 Bark Use - Code
1. Burn as waste
2. Burn as fuel
3. Sell for fuel
4. Give away
5. Chip for agric. use
6. Use for fill
7&8 Space
9. Other

#67 Timberland Ownership - Code
1. Own timberland (land just for the timber)

Form Number 22

Title Softwood Lumber Produced or Used

To be used for Card Number 22,62,72,82

Temporary Number

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10		Card Number	
1		Year data are Pertinent	
2			
3			
4		Space	
5		Annual Size Class - Code*	
6		Actual Annual Production or Consumption - Softwood & Hardwood	
7			
8			
9			
20			
1		Unit - Code *	
2		Utilization - Code *	
3		Softwood % of Total Produced or Used	
4			
5		Balsam-fir	% OF SOFTWOOD
6			
7		Red Cedar	
8			
9		White Cedar	
30			
1		Hemlock	
2			
3		J. Pine	
4			
5		R. Pine	
6			
7		W. Pine	
8			
9		Spruce	
40			

*See Instructions for Code

Instructions

#15 Annual Size Class - Code
0. Idle
1. 1 - 49
2. 50 - 99
3. 100 - 249
4. 250 - 499
5. 500 - 999
6. 1,000 - 1,999
7. 2,000 - 4,999
8. 5,000 - 9,999
9. 10,000 & over

#21 Unit of Measurement - Code
1. MBF
2. Cords
3. Tons
4. M cubic feet
5. Pieces
6. Lineal feet
7. M square feet
8. Space
9. Other

#22 Utilization - Code
1. Produced
2. Consumed
3. Purchased

Column Number			
1		Tamarack or Larch	SOFTWOOD GRADES BY %
2			
3		Cypress	
4			
5		Southern Pine	
6			
7		Other Softwoods	
8			
9		% of Annual Production	
50		in softwood ties	
1			
2			
3			
4			
5			
6			
7		"D" Sel & Better	
8			
9		Shop	
60			
1		#1 Common	
2			
3		#2 Common	
4			
5		#3 Common	
6			
7		# 4 Common & Poorer	
8			
9		Ungraded	
70			
1		Other	
2			
3			
4			
5			
6			
7			
8			
9			
80		Major Product - Code *	

#80 Major Product - Code
1. Sawn Products
2. Veneer
3. Plywood

Form Number 23

Title Hardwood Lumber Produced or Used

To be used for Card Number 23, 63, 73, or 83

Temporary Number

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10		Card Number	
1			
2		Year data are Pertinent	
3			
4		Space	
5		Annual Size Class - Code *	
6		Actual Annual Production or Consumption - Softwood & Hardwood	
7			
8			
9			
20			
1		Unit - Code *	
2		Utilization - Code *	
3		Hardwood % of Total Produced or Used	
4			
5		Ash	% OF HARDWOOD
6			
7		Aspen	
8			
9		Basswood	
30			
1		Beech	
2			
3		Birch	
4			
5		Cherry	
6			
7		Cottonwood	
8			
9		Elm	
40			

*See Instructions for Code

Instructions

#15 Annual Size Class - Code
0. Idle
1. 1 - 49
2. 50 - 99
3. 100 - 249
4. 250 - 499
5. 500 - 999
6. 1,000 - 1,999
7. 2,000 - 4,999
8. 5,000 - 9,999
9. 10,000 & over

#21 Unit of Measurement - Code
1. MBF
2. Cords
3. Tons
4. M cubic feet
5. Pieces
6. Lineal feet
7. M square feet
8. Space
9. Other

#22 Utilization - Code
1. Produced
2. Consumed
3. Purchased

Column Number			
1		Hickory	PROCESSED
2			
3		Hard Maple	
4			
5		Soft Maple	
6			
7		Red Oak	
8			
9		White Oak	
50			
1		Black Walnut	
2			
3		Yellow Poplar	
4			
5		Gum	
6			
7		Sycamore	
8			
9		Other Hardwoods	
60			
1		% of Annual Production in Hardwood Ties	
2			
3		Firsts - Seconds or Select & Better	HARDWOOD GRADES BY %
4			
5		#1 Common & Better	
6			
7		#1 Common	
8			
9		#2 Common	
70			
1		#3 Common	
2			
3		Ungraded	
4			
5		Other Hardwood Grades	
6			
7			
8			
9			
80		Major Product - Code *	

#80 Major Product - Code
1. Sawn products
2. Veneer
3. Plywood

Form Number 24

Title Marketing

To be used for Card Number 24

Column Number			
1		State Code Number	IDENTIFICATION CODES
2			
3		First Letter of Co. or Family Name	
4			
5		Code Numbers to be entered in State Office	
6			
7			
8		Industry Code Classification	
9			
10	2	Card Number	
1	4		
2		Year data are Pertinent	
3			
4		Space	
5		Mill Status - 0. Idle 1. Active	
6		Used by Producer, to nearest 10%	
7		Local Sales (Within 25 miles) to 10%	
8		Within State to 10%	
9		Outside State to 10%	
20		Custom Sawing to 10%	
1		Space	
2		Average Distance to Market (miles)	
3			
4			
5		Sale Basis Chips or Slabs, Rank 1 - Code *	
6		Sale Basis Chips or Slabs, Rank 2 - Code *	
7		Delivery Distance of Chips or Slabs in Miles	
8			
9			
30		Transportation Method - Code *	
1		Weight of Slabs or Chips Shipped in Year (Tons)	
2			
3			
4			
5		Weight of Slabs per MBF Produced (100 lb. units)	
6			
7		Delivery Price of Slabs or Chips (Hardwood)	
8			
9			
40			

* See Instructions for Code

Instructions

#25 - 26 Sale Basis, Chips or Slabs - Code
1. Green ton
2. Dry ton
3. Cord
4. Unit of 2,400 lbs.
5. Load
6-8 Space
9. Other

#30 Transportation Method - Code
1. Rail
2. Truck
3. Barge
4-8 Space
9. Other

Column Number		
1		Space
2		Delivery Price of Slabs
3		or Chips
4		(Softwood)
5		
6		Delivery Price of
7		Chips or Slabs
8		(Aspen)
9		
50		Chip or Slab Pricing Unit - Code *
1		Space
2		Logs Graded
3		Other Roundwood Products Handled - Code *
4		
5		
6		
7		
8		
9		
60		
1		
2		
3		
4		
5		
6		
7		
8		
9		
70		
1		
2		
3		
4		
5		
6		
7		
8		
9		
80		

Temporary Number

#50 Chip or Slab Unit - C
1. Ton
2. Unit
3. Cord

#53 Other Roundwood Produ Handled - Code
1. Sell veneer logs
2. Sell pulpwood incl.
3. Sell poles & piling
4. Sell veneer logs &
5. Sell pulp, poles & pi
6. Sell veneer, pulp, p and piling
7. Tie Cuts
8. Space
9. Other

Form Number 25

Title Products Produced or Used

To be used for Card Number 29-39-41-59-60-74-80

Temporary Number

Column Number		
1		Flake & Particle Board
2		Excelsior Board
3		Excelsior
4		Shavings
5		Chips
6		Posts *
7		Poles *
8		Piling *
9		Charcoal 1. Bulk 2. Briquette
50		Distilation or Extractive Products
1		Wood Flour
2		Other
3		Type * (PLYWOOD)
4		Finish * (PLYWOOD)
5		Major Products * (PLYWOOD)
6		Handles
7		Millwork, Moulding (Inc. Doors, Ladders)
8		Flooring
9		Shakes and Shingles
60		Pallets
1		Boxes and Crates
2		Cooperage
3		Furniture
4		Fixtures-(Bars, Counters, etc.)
5		Cabinets-(Kitchen, TV, etc.)
6		Turned Products (Dowels, Bobbins, etc.)
7		Toys and Novelties
8		Buildings (Mobile, Prefab, trusses)
9		Agricultural
70		Recreation *
1		Broker
2		Wholesaler
3		Retailer
4		Manufacturer
5		
6		
7		
8		
9		
80		

IDENTIFICATION CODES

- State Code Number
- First Letter of Co. or Family Name
- Code Numbers to be entered in State Office
- Industry Code Classification
- Card Number

Year data are Pertinent

INTERMEDIATE PRODUCTS

- Blanks for sporting or Rec. Products *
- Blanks for Handles *
- Core Stock (Lumber) *
- Cooperage Stock *
- Pallet parts or shook *
- Box Shook or Crating *
- Timbers-(Bridge, Mine shoring, ties, etc) *
- Lumber *
- Fencing parts (slats incl. Planks, Pickets, etc.) Lath *
- Furniture or Turning Squares *
- Furniture Parts (Machined) *
- Other-Record Details on back of Form *

VENEER

- Face *
- Core or Back *
- Container *
- Flat or Specialty *
- Pulp *

PAPER

- Newsprint *
- Book & Printing *
- Fine (Stationery, etc.) *
- Coarse (Wrapping, etc.) *
- Special Industrial Absorbent (Felt) *
- Sanitary Tissue *
- Other Tissue *

FIBERBOARD *

- Container Board
- Hardboard
- Insulation Board

* See Instructions for Code

Instructions

#14-25 - Code
1. Hardwood Rough
2. Softwood Rough
3. Both Rough
4. Hardwood Surfaced
5. Softwood Surfaced
6. Both Surfaced
7. Hwd Rough & Surfaced
8. Sftwd. Rough & Surfaced
9. Both Rough & Surfaced

#26-29 - Code
1. Unspliced 8' & longer
2. Unspliced under 8'
3. Unspliced all lengths
4. Spliced 8' & longer
5. Spliced under 8'
6. Spliced all lengths
9. Other

#30 - Pulp - Code
1. Chemical
2. Groundwood
3. Both chemical and Groundwood
4. Semi-chemical
5. Defibrated or Exploded

#31-37 - Code
1. Uncoated
2. Coated
3. Both coated and uncoated
4. Corrugated

#38 - 45 - Code
0. None
1. Used
2. Produced

#46-48 - Code
1. Untreated
2. Treated
3. Both Untreated and Treated

#53 Plywood Type
1. Hardwood Face Plywood
2. Hardwood Nonface (Not Container)
3. Hardwood Both of above
4. Hardwood Container
5. Softwood Face
6. Softwood Construction
7. Softwood Both of Above
8. Softwood Container
9. Hardwood & Softwood Plywood

#54 Plywood Finishing
1. Unfinished panels
2. Prefinished panels
3. Both unfinished and Prefinished panels
4. Unfinished curved or moulded
5. Prefinished curved or moulded
6. Both unfinished and prefinished curved
7. Both unfinished panels and curved
8. Both prefinished panels and curved
9. Other

#55 Plywood Products
1. Wall panels
2. Door Skins
3. Both wall panels and door skins
4. Flooring
5. Cabinet parts (Kitchen, TV, etc.)
6. Furniture parts
7. Machined or turned parts

#70 Recreation Items - Code
1. Hunting (Incl. Archery)
2. Fishing (Incl. boats)
3. Water sports
4. Golf
5. Playground - Court
6. Gymnasium
7. Bowling, pool, etc.
8. Skiing (winter)
9. Other

Wood-Using Industry Directory

Extracts of sections of the Minnesota Wood-Using Industry Directory as printed out by the computer from cards punched according to the described system are shown in the following illustrations:

PRODUCERS OF ROUNDWOOD
(LOGGERS)

NAME OF PRODUCER ADDRESS PHONE NUMBER	SPECIES*	PRODUCTS PRODUCED	VOLUME* CLASS	COUNTY
ANDERSON, TOIVO MC GREGOR, MINN. 55760	ASP, SPR, BAL, HDWDS.	PULPWOOD SAWLOGS VENEER LOGS	B C A	AITKIN
BOTTILLA, SULO MORA, MINN. 55051	ASH, ELM, MAP, BIR, BASS.	SAWLOGS POSTS & POLES	A H	KANABEC
CALLIO, JOHN LOMAN, MINN. 56654 PH: 218-456-1475	JP, CED.	POSTS & POLES	D	KOOCHICHING

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

SAWMILLS

NAME OF SAWMILL ADDRESS PHONE NUMBER	SPECIES*	PROD. SIZE CLASS	TYPE OF SAWMILL	OTHER EQUIPMENT	COUNTY
ANDREWS, SAM SEBEKA, MINN. 56477	ASP, JP, MAP, BASS, OAK.	D	STATIONARY	DEBARKER CHIPPER PLANER	WADENA
BAKKA, JOE BIG FALLS, MINN. 56627 PH: 218-546-1345	NP, WP, TAM.	B	PORTABLE		KOOCHICHING

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

WOOD PROCESSING INDUSTRIES

(PRODUCTS MADE FROM WOOD)

NAME OF INDUSTRY ADDRESS OF INDUSTRY PHONE NUMBER	SPECIES*	VOLUME USED*	MANUFACTURED PRODUCT	COUNTY
ADAMS PRODUCTS INC. 243 WEST FAIRFIELD AVE. ST. PAUL, MINN. 55107 PH: 612-777-2345	OAK, ASH, BIR.	E	FURNITURE	RAMSEY
BACKS LOG CABIN IND. LA PORTE, MINN. 56461 PH: 218-435-6723	NP, WP, JP, WHS.	F	PRECUT LOG CABINS	CROW WING
COMLINSON LBR. CO. CALLOWAY, MINN. 56521 PH: 218-4659	ASP, MAP, BASS, OAK.	C	FEEDERS PALLETS	AITKIN

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

WOOD USING INDUSTRIES

(AS A RULE, WOOD IS NOT A MAJOR PART OF THE MANUFACTURED PRODUCT.)

NAME OF INDUSTRY ADDRESS OF INDUSTRY PHONE NUMBER	SPECIES*	VOLUME USED*	WOOD PRODUCTS PURCHASED	COUNTY
ARMCO STEEL METAL CO. 4345 LYNDALE AVE. NO. MPLS., MINN. 55412 PH: 612-468-4259	ASP, WEST.	C C	PALLETS LUMBER	HENNEPIN
TORO MFG. COMPANY 8111 LYNDALE AVE. SO. MPLS., MINN. 55420	BIR, OAK.	B	LUMBER-SQUARES	HENNEPIN
WEST CENTRAL TURKEYS ANOKA, MINN. 55303	ASP	B C	PALLETS SHAVINGS	ANOKA

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

CHRISTMAS TREE PRODUCERS

NAME OF PRODUCER ADDRESS	SPECIES*	VOLUME PRODUCED*	PRODUCTS PRODUCED	COUNTY
ANTILLA, VICKO JACOBSON, MINN. 55752	NP, WHS. BAL.	C	NATURAL TREES BOUGHS	AITKIN
BULTUS, WILLIAM OUTING, MINN. 56662	NP, SCP, WP.	J	PLANTATION TREES SHEARED TREES	CASS

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

MINNESOTA LUMBERYARDS

NAME OF LUMBERYARD	ADDRESS	SPECIES OF MINN. WOOD HANDLED*	COUNTY
ANDERSON LBR. CO.	MC GRATH, MINN. 56350	ASP, NP, WP, CED.	AITKIN
ANDREWS LBR. CO.	PALISADE, MINN. 56469	TAM, CED.	AITKIN

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

COLLECTORS OF MAPLE SAP

NAME OF COLLECTOR	ADDRESS	PRODUCTION CLASS* (IN GALS.OF SAP)	COUNTY
ANDERSON, ROBERT	MORA, MINN. 55051	C	KANABEC

* SEE CODES ON FLY LEAF IN BACK OF DIRECTORY

Some Recent Research Papers of the North Central Forest Experiment Station

Hardwood Siding Performance, by Glenn A. Cooper. U.S.D.A. Forest Serv. Res. Pap. NC-16, 11 p., illus., 1967.

Quantitative Color Measurement for Black Walnut Wood, by Ali A. Moslemi. U.S.D.A. Forest Serv. Res. Pap. NC-17, 16 p., illus., 1967.

Some Variables Affecting Hardwood Control With Stem Injections of 2,4,5-T, by John L. Arend. U.S.D.A. Forest Serv. Res. Pap. NC-18, 11 p., illus., 1967.

Timber Management Guide for Shortleaf Pine and Oak-Pine Types in Missouri, by K. A. Brinkman and N. F. Rogers. U.S.D.A. Forest Serv. Res. Pap. NC-19, 15 p., illus., 1967.

Selection of Superior Yellow Birch Trees, A Preliminary Guide, by Knud E. Clausen and Richard M. Godman. U.S.D.A. Forest Serv. Res. Pap. NC-20, 10 p., illus., 1967.

Stabilizing Eroding Streambanks in Sand Drift Areas of the Lake States, by Edward A. Hansen. U.S.D.A. Forest Serv. Res. Pap. NC-21, 12 p., illus., 1968.

Paper Birch: Its Characteristics, Properties, and Uses, A Review of Recent Literature, by Matti J. Hyvarinen. U.S.D.A. Forest Serv. Res. Pap. NC-22, 12 p., illus., 1968.

Proceedings of the Eighth Lake States Forest Tree Improvement Conference, September 12-13, 1967. U.S.D.A. Forest Serv. Res. Pap. NC-23, 60 p., illus., 1968.

Shrinkage and Footage Loss from Drying 4/4-Inch Hard Maple Lumber, by Daniel E. Dunmire. U.S.D.A. Forest Serv. Res. Pap. NC-24, 10 p., illus., 1968.

Topography and Soil Relations for White and Black Oak in Southern Indiana, by Peter R. Hannah. U.S.D.A. Forest Serv. Res. Pap. NC-25, 7 p., illus., 1968.

ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

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U.S.D.A. FOREST SERVICE
RESEARCH PAPER NC-27
1969

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THE Influence of Light, Moisture, and Seedbed on Yellow Birch Regeneration

Carl H. Tubbs

NORTH CENTRAL FOREST EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

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Note: The author is Plant Physiologist at the Northern Hardwoods Laboratory, North Central Forest Experiment Station, Marquette, Michigan (field unit maintained in cooperation with Michigan State University).

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The Influence of Light, Moisture, and Seedbed On Yellow Birch Regeneration

Carl H. Tubbs

Yellow birch (*Betula alleghaniensis* Britton) has traditionally been one of the most valuable species in the northern hardwood forest. Its high value has led to many attempts to increase its numbers by planting or seeding or by manipulation of the overstory. Many of these attempts have not been successful.

Yellow birch is found on a variety of sites covering a wide range of moisture conditions and soil types. Although in the Lake States it is nearly always found where northern hardwoods grow, its numbers are generally low. In Wisconsin, Curtis (1959) reported yellow birch to be of greatest importance in wet-mesic stands of mixed hardwood-conifer and on mesic sites dominated by sugar maple. Westveld (1933) found yellow birch universally present on every soil type investigated but found little indication of a soil preference in the Upper Peninsula of Michigan. Linteau (1948) suggested that yellow birch acts both as a pioneer and a member of the climax forest.

The species is adaptable to a wide range of conditions, but the apparent lack of preference for certain soils or environments unfortunately leaves the forester without a point on which to focus attempts to increase the proportion of yellow birch.

Silvical and silvicultural studies have led to conflicting ideas of environmental requirements for regeneration. Godman and Krefting (1960), reviewing these studies, found that overstory recommendations ranged from 30 to 70 percent of full sunlight. Seedbed recommendations emphasized the necessity of seedbed disturbance of some sort, although recommended types of disturbance differed.

These authors showed in their own trials of heavy cutting and scarificaton that, while establishment was excellent on scarified areas where mineral soil was exposed, growth was poor. Subsequent studies of shade requirements showed that moderate (50 percent) shade would be desirable. In a later publication, Godman (1959) pointed out that where the water table remained near the surface, yellow birch establishment was adequate on undisturbed litter.

The ubiquitous occurrence of yellow birch and variety of recommended environments reported by silvicultural studies suggested that seedbed requirements vary depending on light intensity and moisture conditions. To test this hypothesis, a study was designed to show the response of yellow birch regeneration to a variety of environments.

Methods, Materials, and Measurements

The study area was in a small forest opening on the Upper Peninsula Experimental Forest near Skandia, Michigan. Two sites were simulated: a well-drained site and an imperfectly drained site where the water table remains near the surface. The latter was an attempt to duplicate a field condition described by Godman (1959). On each of these sites four light conditions and eight seedbed types were studied. Light conditions were full sunlight and 30, 50, and 75 percent shade. The seedbeds were of four general classes of forest floor material: (1) humus from a nearly pure old-growth upland sugar maple stand, (2) humus from a nearly pure stand of old-growth hemlock, (3) rotten hemlock logs, and (4) humus and upper horizons of a podzol soil occurring under a mixed hardwood-conifer stand. This latter material was subjected to the following treatments: (1) litter burned,[1] (2) litter removed with a rake, (3) litter covered with a 1-inch sawdust mulch (hemlock sawdust), (4) humus removed leaving the leached, sandy A_2 horizon, and (5) undisturbed.

Humus seedbeds generally resembled a matted mor. Sugar maple stands, from which seedbeds were taken, had thin humus horizons (2 inches) while the hemlock and mixed hardwood stands were characterized by a thick humus accumulation (4 to 12 inches). The textural class of the A_2 mineral soil seedbed was sand.

Seedbed samples were cut out of the forest floor in 3-square-foot sections, 5 inches thick, and laid randomly in rows under the various degrees of shade (fig. 1). Seedbeds were isolated from each other by 2 inches of sand. Shade was provided by green plastic screening supported box-like over the beds. On the imperfectly drained site the water table was held near the surface by using subirrigation. On the well-drained site the water table was allowed to fluctuate naturally.

[1] *Burning was done with a blow torch. The L layer was totally decomposed but the moist F and H layers were not visibly affected.*

FIGURE 1. — Blocks were lifted from the surface of the forest floor, transported to the seedbed study area, and placed in trenches. In the bottom photo, the trench on the left is being screened for shading. (F-504372-504371)

Two samples of each seedbed type were subjected to each combinaton of moisture and shade conditions. There were 8 seedbeds, 4 light intensities, and 2 moisture levels in 2 blocks totalling 128 plots.

In November 1961, 200 seeds collected from a single tree were placed on one-third of each bed. Seed placed on the remaining two-thirds were not counted but equal volumes were placed on each seedbed. The counted-seed portion was used to determine germination and mortality while the remaining portion was used for height-growth and seedling production measurements. Height of the five tallest seedlings in each bed was measured at the end of the first growing season. These seedlings were then tagged and height growth was observed periodically throughout the 1963 season. Competing vegetation was clipped at regular, short intervals

On one replication, gravimetric moisture samples were taken periodically and air and ground-surface temperatures were recorded as well. Soil moisture of the organic seedbeds was measured by weighing baskets of the seedbed material. These containers were 4-inch-square plastic berry baskets cut to 1½-inch depth and lined with nylon netting fine enough to prohibit movement of humus but not fine enough to inhibit moisture movement.

A block of the seedbed the size of the basket was carefully cut out and placed in the basket. The basket was then replaced in the resulting hole. At weekly intervals from June through August each basket was removed and weighed. Material was dried and weighed during the following winter.

Tests of the reliability of the basket samples were made by sampling with a core sampler on two different dates. The correlation coefficient between basket and core samples was 0.84.

Surface temperatures were measured on selected days with thermistors; air temperatures were continuously observed by means of a recording thermograph in a weather shelter; and minimum and maximum thermometers were read daily in each shade condition.

Results

Temperature and Moisture

Temperature and moisture within the various environments generally followed predictable patterns. In full sunlight, mineral soil surfaces (A_2 horizon) were much cooler than organic surfaces on which temperatures as high as 150° F. were recorded. Temperatures were higher above the organic material, too: at 2 cm. above the organic material, temperatures rose to 128° compared to 100° F. for the A_2. At 10 cm., differences were slight.

Even though shading reduced surface temperature on the organic beds, temperature in excess of 110° F. occurred under shade on the well-drained site (table 1). Temperature tended to rise and fall less rapidly under shade than it did in the open.

Table 1. — Undisturbed mixed hardwood leaf surface temperatures on the well-drained site on a clear day

(In degrees F.)

Time	Full sunlight	50 Percent shade	75 Percent shade
3:45 p.m.	127	95	90
5:21 p.m.	102	92	89
8:23 p.m.	57	59	62
11:35 p.m.	55	56	59
5:00 a.m.	50	53	57
7:35 a.m.	75	75	67
10:47 a.m.	110	103	95
Noon	125	115	110
1:59 p.m.	90	110	108
3:30 p.m.	85	95	100
4:15 p.m.	90		95

On the imperfectly drained site, organic surface temperature in full sunlight rose to about the same height as on the well-drained site but somewhat later (approximately ½ hour) and remained above 120° for about 2½ hours in contrast to the drier situation where temperature remained above 120° for only 45 minutes.

Temperature measurements on a similar clear day on A_2 mineral soil show about the same pattern but at a lower level (table 2). During the day, temperature was lower on the imperfectly drained sites but at night was slightly higher than on the well-drained site.

Freezing temperature was recorded at the weather station in each month of the growing season except July. Minimum thermometers located 2 feet high under three of the shade conditions indicated that increasing shade density increased the minimum temperature readings. Temperatures below freezing were recorded five times under 25 percent shade, four times under 50 percent shade, and once under 75 percent shade.

Precipitation patterns differed for the 2 years of the experiment. During 1962, about 6 inches of rain fell from June through August. The same period in 1963 produced over 9 inches (table 3).

Rainfall under each shade condition was measured during the first growing season. Usually the densest shade resulted in the least throughfall.

Table 2. — A_2 mineral soil surface temperatures by drainage class, time of day, and degree of shade on a clear day

(In degrees F.)

Shade (percent)	Noon		Midnight		4:00 a.m.	
	Well-drained	Imperfectly drained	Well-drained	Imperfectly drained	Well-drained	Imperfectly drained
0	101	91	60	62	63	65
30	89	88	62	64	64	65
50	86	80	61	59	63	60
75	82	79	63	64	65	65

Table 3. — Growing-season precipitation

Month	1962		1963		Normal
	Rainfall	Days rain recorded	Rainfall	Days rain recorded	Rainfall
	Inches	Number	Inches	Number	Inches
June	1.79	12	4.16	16	3.62
July	1.09	9	2.38	12	3.16
August	3.15	12	2.82	12	3.24
Total	6.03	33	9.36	40	10.02

1/ Michigan State University Experiment Station, Chatham, Mich. (10 miles east of the Upper Peninsula Experimental Forest).

The imperfectly drained site averaged twice as much seedbed moisture as the well-drained, and moisture content was more uniform on the imperfectly drained site both by time and treatment except for the full sunlight treatment which generally resulted in much lower moisture. Moisture content fluctuated greatly on the well-drained site but was higher under shade (fig. 2).

Germination

Clearcut differences in germination between degrees of shade, seedbeds, and moisture indicated that germination was favored by the cooler, moister environments (table 4).

The imperfectly drained site had the most germination. The mineral-soil seedbed proved to be the best for germination on the well-drained site. But on the imperfectly drained area four other seedbeds had higher germination under one or more of the shade conditions.

Least germination occurred in full sunlight; only the A_2 supported even a moderate amount of germination in this environment. Moderately heavy shade was best for germination on the well-drained site while lighter shade was best on the imperfectly drained site (fig. 2). This is particularly true of disturbed seedbeds on the latter site.

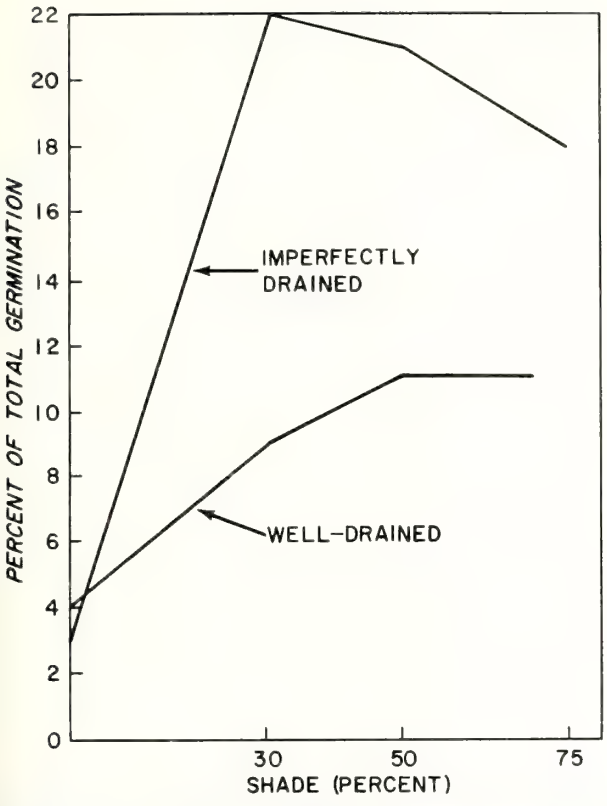

FIGURE 2. — Total germination by shade and drainage.

Mortality

A continuation of the cool, moist environment was necessary to prevent seedling mortality early in the first growing season. In general, the same seedbed, light, and moisture conditions that favored germination also resulted in the lowest mortality.

Thirty percent of the seedlings died during the first growing season. Mortality was highest shortly after germination: 70 percent of the total mortality occurred before the first of July. The chief causes of early mortality appeared to be heat and drought; the most severe mortality was on seedbeds in full sunlight (table 5). Thus the lower temperatures of the mineral soil beds may have been responsible for the better survival here than on organic seedbeds during the period shortly after germination.

Insects and frost also contributed to mortality during the first growing season. Insects damaged 20 percent of seedlings before the first of July and were directly responsible for minor losses. Probably insects weakened plants which were subsequently killed by extremes of temperature or moisture. Several periods of freezing at night occurred during the spring but caused only minor losses.

About 60 percent of the seedlings remaining at the end of the first growing season were dead at the end of the second growing season. Of these, only 20 percent died during the main part of the second growing season; 80 percent of the mortality occurred between growing seasons and shortly after the start of the second season, apparently caused by frost.

Frost damage occurred in the fall before plants had become dormant[2] and again in the spring immediately after buds began flushing. In general, frost damage was least under moderate shade although result are variable. Except for seedlings growing in full sunlight, damage was less on the imperfectly drained site than on the well-drained (table 6). The type of seedbed did not influence this general pattern; however, seedlings growing on rotten logs and on mineral soil suffered little frost damage.

It is interesting to note that under full sunlight and 30 percent shade, frost-damaged seedlings grew better than those not damaged (table 7). Under the heavier shades, frost-damaged seedlings grew about the same or slightly less than undamaged seedlings.

Survival under shade the second year was similar to that of the first with best survival under moderate shade except that seedlings on mineral soil were essentially the only survivors in full sunlight. However, losses on mineral soil were substantial in the rest of the environments. Survival on this seedbed was next to lowest.

[2] *The first year terminal buds were not set on most seedlings. However, the second year the top bud on approximately half of the seedlings appeared to have become dormant. Variation in dormancy did not appear to be related to environment.*

Table 4. — Yellow birch germination by shade and seedbed, 1962

(In numbers)

Shade (percent)	Rotten hemlock log	Undisturbed hemlock duff	Undisturbed sugar maple	Mixed hardwood-conifer humus: Undisturbed	Burned	Raked	Hemlock sawdust mulch	A_2 horizon	Total
WELL-DRAINED									
0	11	1	1	1	4	4	0	25	47
30	4	17	5	16	3	4	15	37	101
50	26	17	8	2	5	4	8	57	127
75	10	23	3	42	7	11	9	21	126
Total	51	58	17	61	19	23	32	140	401
IMPERFECTLY DRAINED									
0	2	4	2	3	2	7	4	12	36
30	39	18	12	29	68	22	22	36	246
50	50	39	8	55	41	9	4	33	239
75	62	32	26	18	11	15	13	26	203
Total	153	93	48	105	122	53	43	107	724
Grand total	204	151	65	166	141	76	75	247	1125

Table 5. — First-year seedling mortality, by shade and seedbed, 1962

(In percent)

Shade (percent)	Rotten hemlock log	Undisturbed hemlock duff	Undisturbed sugar maple	Mixed hardwood-conifer humus: Undisturbed	Burned	Raked	Hemlock sawdust mulch	A_2 horizon	Average all seedbeds
WELL-DRAINED									
0	91	100	100	100	75	75	0	52	68
30	25	25	60	27	0	25	43	18	28
50	15	24	12	100	100	0	25	32	24
75	10	35	0	37	100	36	89	59	44
Average	31	29	30	27	74	35	50	35	35
IMPERFECTLY DRAINED									
0	(1/)	0	100	33	0	43	100	25	42
30	48	33	27	11	80	0	15	14	37
50	9	11	12	28	5	11	0	10	12
75	37	10	48	28	10	15	0	35	28
Average	29	24	38	20	47	11	16	19	26

1/ Data incomplete.

Table 6. — Yellow birch injured from fall 1962 and spring 1963 frosts, by shade and site

(In percent)

Shade (percent)	Well-drained		Imperfectly drained	
	Moderate injury	Severe injury	Moderate injury	Severe injury
0	64	21	62	30
30	41	34	36	13
50	51	38	30	22
75	67	33	34	22
Weighted average	53	35	38	20

Seedling Production

After 2 years, seedling production on the imperfectly drained site was twice that on the drier area (table 8); under imperfectly drained conditions numbers were greatest under 30 percent shade on disturbed beds. Other seedbeds showed variability but in general produced more seedlings under 50 to 75 percent shade (fig. 3).

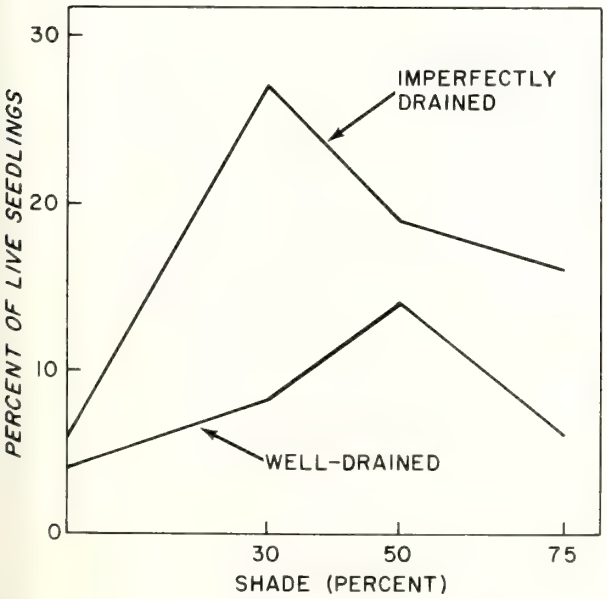

FIGURE 3. — Live seedlings remaining after the second growing season by site and shade.

Table 7. — Average growth (1963) of seedlings by degree of frost damage

Shade (percent)	None	Moderate	Severe
0	0.46	0.56	0.52
30	.72	.79	.85
50	.68	.67	.61
75	.68	.59	.67

About one-third of the seedlings were found on mineral soil beds. However, mineral soil did not support significantly more seedlings in several environments — its superiority appeared to be limited to the drier, less shaded environments.

Height Growth

More moisture on the imperfectly drained site resulted in greater height growth, especially during the first growing season. The second year the superiority of the imperfectly drained site was less and differences between seedbeds also diminished, particularly among the organic seedbeds (table 9). Increased height growth the second year on the well-drained site may have been due to the greater precipitation that year.

Seedbed effect differed according to moisture treatments the first year. Seedlings growing on hemlock logs, mulched mixed-hardwood-conifer, and A_2 horizon on the imperfectly drained site grew no faster than those on the well-drained site. While several explanations are possible, it appears that the corresponding seedbeds on the well-drained site were adequately supplied with moisture.

Although height growth was generally best under 30- and 50-percent shade, two distinct height-growth/shade patterns developed during the experiment (fig. 4). Seedlings growing on well-drained mineral soil and on burned mixed-hardwood litter grew better under full sunlight than under any shade. In contrast, on the imperfectly drained site,

Table 8. — Yellow birch seedlings remaining after the 1963 growing season

(In numbers)

Shade (percent)	Rotten hemlock log	Undisturbed hemlock duff	Undisturbed sugar maple	Mixed hardwood-conifer humus: Undisturbed	Burned	Raked	Hemlock sawdust mulch	A_2 horizon	Total
WELL-DRAINED									
0	0	1	2	5	3	1	2	63	77
30	3	26	15	25	12	8	15	37	141
50	11	14	23	12	8	24	15	136	243
75	0	13	21	30	6	6	1	4	81
Total	14	54	61	72	29	39	33	240	542
IMPERFECTLY DRAINED									
0	0	7	6	3	1	13	1	63	94
30	6	55	17	46	66	91	93	98	472
50	20	62	52	64	40	16	6	72	332
75	59	67	22	33	26	5	11	55	278
Total	85	191	97	146	133	125	111	288	1176
Grand total	99	245	158	218	162	164	144	528	1718

Table 9. — Average total height of 5 tallest 2-year-old yellow birch, 1963

(In feet)

Shade (percent)	Rotten hemlock log	Undisturbed hemlock duff	Undisturbed sugar maple	Mixed hardwood-conifer humus: Undisturbed	Burned	Raked	Hemlock sawdust mulch	A_2 horizon	Average
WELL-DRAINED									
0	– 1/	–	–	0.66	1.45	0.90	0.47	.66	.83
30	0.94	1.00	1.03	1.29	.96	1.12	1.23	.28	.98
50	1.11	.98	1.21	1.10	1.18	.99	1.16	.25	1.00
75	–	.47	.95	1.36	1.02	.92	–	.11	.81
Average	1.03	.82	1.06	1.10	1.15	.98	.95	.33	.91
IMPERFECTLY DRAINED									
0	–	.88	.76	1.01	.69	.98	.74	.20	.75
30	.85	1.64	1.15	1.64	1.84	.80	1.55	.72	1.27
50	.90	1.48	1.18	1.50	1.39	.62	1.04	.24	1.04
75	.46	1.30	.91	1.39	1.56	1.15	1.04	.26	1.01
Average	.73	1.33	1.00	1.39	1.37	.89	1.09	.36	1.02

1/ No survival.

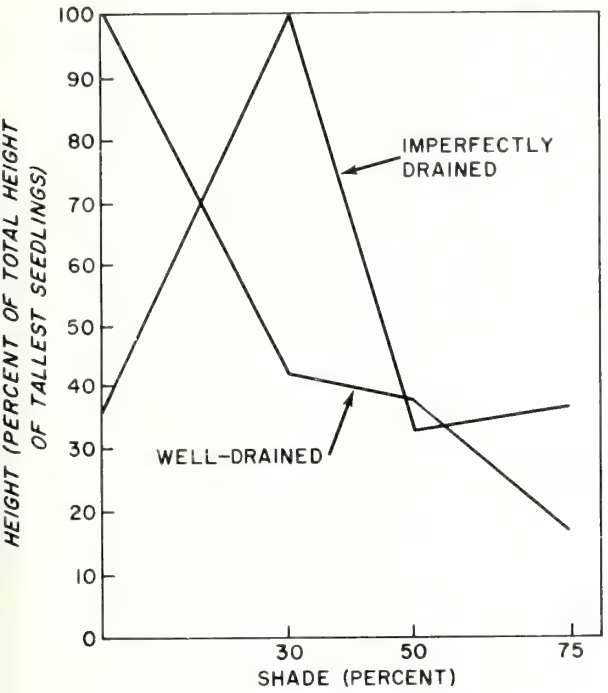

FIGURE 4. — Percent total height of tallest seedlings on A_2 seedbed by moisture and shade.

these seedbeds produced the tallest seedlings under moderate (30- to 50-percent) shade. The other seedbed conditions consistently produced taller seedlings under moderate shade regardless of the moisture.

To attempt an explanation of this moisture and interaction seedling dry weights were recorded and a few morphological features of leaves were measured on plants growing on the A_2 horizon under two shade and moisture conditions. The imperfectly drained mineral-soil seedbed produced plants with leaves generally larger than those of seedlings growing on the well-drained site. Leaf thickness was relatively insensitive to shade on the imperfectly drained site while the reverse was true of the well-drained site.

Using leaf area per gram of seedling (dry weight) as a measure of efficiency of production, we found that although shade has an influence (leaf areas/gram of dry weight doubled or tripled from no shade to 75 percent shade), the largest differences in leaf area per gram dry weight (14 fold differences) resulted from the difference in moisture.

Discussion

Unfortunately, germination tests were not repeated during the second and wetter year of the experiment but it seems reasonable to suppose that cloudy, cool, and wet years might result in good germination and survival in environments that were less than favorable in this study. It is likely that this factor also contributes to the ubiquitousness of the species.

The relatively high survival in full sunlight on the A_2 mineral soil had also been recorded in a study reported by Linteau (1948). This droughty environment probably resulted in a condition long known to nurserymen as "hardening." Plants subjected to drought or prolonged chilling are known to be more resistant to both drought and cold injury. Plants developing in full sunlight are usually considered to be more resistant to heat injury than those grown in shade (Gatherum, *et al.* 1963). The results of these adaptations may be masked by the physical environment, however. For example, one would have expected higher mortality on the imperfectly drained site, particularly under shade. Although these moist conditions should have resulted in less "hardy" plants, high moisture and shaded conditions reduced the occurrence and the intensity of extreme temperatures. The deepest shade (75 percent), however, apparently produces seedlings that are least likely to survive.

Some studies have shown frost to be a negligible factor in yellow birch survival (Godman and Krefting 1960) while others (Linteau 1948) have found frost to be serious. The apparent contradiction may be due to variation in moisture regimes. This study indicates that a wet-mesic site location might be expected to reduce damage, probably by reducing the intensity and duration of frost in contrast to a more mesic site. Although our study does not show this, it is well known that relatively wet, cool, environments delay plant growth in the spring which may additionally help protect yellow birch seedlings on wet mesic sites.

Seedlings on undisturbed seedbeds on the imperfectly drained site seemed to require more shade than those on disturbed seedbeds. Undisturbed seedbeds with leaf litter are known to reduce both germination and early survival (Koroleff 1954). Part of the explanation may be that reduced temperatures and evaporation rates caused by increased shade help offset the effect of the undisturbed litter.

The two height-growth patterns recorded in this study have also been observed in field studies. Height growth of seedlings growing on an imperfectly drained area (Godman and Krefting 1960) on mineral soil was favored by shading. In field studies on well-drained sites (Linteau 1948 and Jarvis 1957), best height growth of yellow birch was in full sunlight. Variations in height growth by moisture conditions have also been observed by Wang (1965).

The general similarity between characteristics of plants subjected to high light levels or low soil moisture suggests that either of these factors may result in the same response by the plant. For example, Henckel (1964) citing work by Konaren pointed out that the development of xeromorphic characteristics could be stimulated by deficiencies of phosphorus or moisture or high light levels. If physiological phenomena controlling plant size are similarily governed, this might provide an explanation for the two growth patterns observed. For example, photosynthetic capabilities of sun and shade leaves usually vary in predictable patterns (Kramer 1958): sun leaves are more productive under high light intensities than shade leaves. The relatively more shade-like leaves produced on the imperfectly drained site of this study thus may have been less efficient in full sunlight than the more sun-like leaves of the well-drained site, at least on the mineral A_2. Our preliminary study of some features of the leaves of yellow birch seedlings grown on the mineral A_2 suggests that this may be part of the reason for height growth reduction of seedlings grown under the influence of a high water table in full sunlight.

The results of this study provide an explanation for the heavy stocking of yellow birch observed by foresters and ecologists along forest roads and logging skid trails. Road building and logging open the canopy resulting in partial shade, destroy advance growth of tolerant seedlings, and expose mineral soil which results in good germination. Optimum growth, however, often depends on the plant's ability to root in the humus and most often the birch closest to the edge separating forest and disturbed conditions seem to be the most successful. Data from Godman and Krefting (1960) illustrate this further: they show that partially scarified areas resulted in more large birch than those totally scarified. The partly scarified area resulted in a greater amount of the humus-mineral soil edge which probably provided both a good environment for germination and for growth. In this connection, it should be mentioned that several investigators have noted the beneficial effects of humus-mineral soil mixtures on germination and growth (Godman and Krefting 1960; Tubbs 1963; and Wang 1965) and on root-shoot ratios (Tubbs and Oberg 1966).

Several authors have considered site disturbance the key factor in explaining the occurrence of yellow birch (Winget *et al.* 1965). The results of this study show that seedbed disturbance may usually be necessary for regeneration on well-drained sites but not on imperfectly drained sites if overhead light is available. Future development of seedlings may be retarded in the wettest situations, however, since species lists from Curtis (1959) show that both importance values and constancy fall drastically proceeding from wet-mesic to wet forests. Braun (1950) indicated a similar pattern in forest communities of the Tahquamenon Wilderness of Upper Michigan.

Summary — Conclusion

The hypothesis that seedbed requirements of yellow birch can vary with changes in light intensity and moisture conditions has been supported by this experiment. In addition, it was found that requirements changed with each stage of development.

Seedbed requirements for good germination were variable depending on light and moisture:

	Shade		
Site	*Full sun*	*Moderate shade*	*Heavy shade*
Well-drained	Mineral soil	Mineral soil	Heavy and organic
Imperfectly drained	Mineral soil	Both mineral and organic	Both mineral and organic

First year mortality was primarily due to heat and drought. Although results were variable full sunlight was detrimental on all seedbeds but the mineral A_2 seemed to provide a consistently better environment for survival under this shade condition. Least heat-and-drought caused mortality occurred under moderate shade on the imperfectly drained site.

Frost was the most serious cause of mortality thereafter. Seedbed was not a major factor but shade and moisture conditions influenced damage. Least damage occurred under moderate shade on the imperfectly drained site.

The combined effects of germination and survival resulted in highest production of seedlings on the A_2 mineral soil on the well-drained site particularly under moderate shade while on the imperfectly drained site several other seedbed, light combinations come close to equaling or surpassed A_2 production. Best production was under moderate shade for any seedbed. The A_2 was the only successful seedbed in full sunlight on either site.

Height growth was best on organic seedbeds. On these seedbeds moderate shade was generally necessary for best growth. The imperfectly drained site produced the tallest seedlings on these seedbeds under moderate shade. Maximum growth occurred on burned mixed-hardwood-conifer seedbeds under moderate shade on the imperfectly drained site. On mineral soil seedlings grew best in full sunlight on the well-drained site while shade was necessary for best height growth on the imperfectly drained site.

Yellow birch can germinate, survive, and grow satisfactorily in a number of environments. Its potential includes exposed sites as well as those that are cool, moist, and shaded. Seedbed disturbance is necessary on drier sites or during dry periods while partially shaded wet-mesic situations offer the necessary cool, moist environment without seedbed disturbance. Seedbed disturbance also is required during years of normal or subnormal precipitation when full sunlight prevails regardless of moisture conditions of the site.

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PRESCRIBED BURNING WEATHER IN MINNESOTA

Rodney W. Sando

NORTH CENTRAL FOREST EXPERIMENT STATION
U. S. DEPARTMENT of AGRICULTURE
FOREST SERVICE

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NOTE: The author is Associate Fire Control Scientist for the Station which is maintained in cooperation with the University of Minnesota.

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Prescribed Burning Weather in Minnesota

Rodney W. Sando

Prescribed or controlled burning is becoming a widely used forest management tool in the Lake States region. The traditional reluctance of wildland managers to use controlled burning, brought about by a history of devastating fires, is changing. As the use of prescribed burning continues to expand, definite guides for achieving each particular objective will be needed.

Successful prescribed burning calls for comprehensive planning and skillful execution. Planning a burn requires, among other things, some knowledge about the seasonal occurrence of the necessary weather conditions. Unless weather favorable to the use of fire occurs with some regularity every year, prescribed burning cannot become a truly reliable tool.

The annual precipitation pattern is probably the key factor determining the time of year prescribed burning can be done. Wind (both speed and direction) is another important weather element to be accounted for in planning prescribed burns. Wind direction in the Lake States is determined more by synoptic weather than by topographical features, so definite seasonal wind patterns do occur.

A study was made to determine patterns of weather variables influencing prescribed burning in Minnesota during the period from April to mid-November. The results of this study should be used as a guide for planning purposes only and should not be treated as a long-range weather forecast.

VARIABLES AFFECTING PRESCRIBED BURNING

The success of a prescribed burn depends greatly on the weather both before and during the burn. The most important weather variables to consider are air temperature, relative humidity, wind direction, windspeed, and precipitation. The combination of temperature and relative humidity will largely determine the moisture content of cured fine fuels. These fine fuels are important in fire spread and behavior, particularly influencing the occurrence of spot fires.

Wind direction is critical in planning a prescribed burn. Most preburn preparations such as firebreaks or fuel modifications are oriented according to a specific wind direction. Selection of the wind direction required should be determined by both the physical characteristics of the proposed burn area and the probability of the wind coming from the chosen direction on a day suitable for burning.

Windspeed is also important. Prescribed burning is generally not attempted when the windspeed exceeds 20 m.p.h., and most plans will specify a maximum allowable windspeed less than 15 m.p.h.

The number of days since significant amounts of precipitation have occurred is often used in burning prescriptions. In addition, the National Fire Danger Rating Buildup Index is used by many fire control agencies. The Buildup Index, accounts for the cumulative effects of temperature, humidity, and precipitation and can be used as an indicator of the moisture content of coarse fuels. A minimum acceptable Buildup Index is usually established for each prescribed objective. Although the magnitude of the Buildup Index has important effects on the results, plans for prescribed burning should not be written using only the Buildup Index as an indicator of the desired weather conditions; ranges for other factors such as temperature, wind speed, and relative humidity must be specified.

METHODS

Weather data for the period from April 1 to November 15 were obtained from the National Weather Records Center in Asheville, North Carolina. The data covered 10 years from 1955 through 1964 and were obtained for Minneapolis, Duluth, and International Falls. Each daily record consisted of nine hourly records for the hours from 10:00 a.m. to 6:00 p.m. and a summary record for the entire day. Wind directions were recorded for each hour using 16 points on the compass.

The National Fire Danger Rating Fine Fuel Spread Index and Timber Spread Index (Nelson 1964)[1] were computed for each of the 9 hours, and the Buildup Index (Nelson 1964) was computed for each day using the daily precipitation summary and the 1:00 p.m. wet and dry bulb temperature, and windspeed.

Seasonal herbaceous stages required for the computation of the indexes were established for each station by using a 4-year average of the dates used by the State of Minnesota's Division of Forestry station nearest each weather station for which records were obtained.

The dates used are as follows:

Minneapolis	
Spring	4/1 — 5/5
Spring transition	5/6 — 5/17
Summer	5/18 — 9/27
Fall transition	9/28 — 10/22
Fall	10/23 — 11/15
Duluth and International Falls	
Spring	4/1 — 5/12
Spring transition	5/13 — 5/27
Summer	5/28 — 9/21
Fall transition	9/22 — 10/16
Fall	10/17 — 11/15

Many days each year have weather conditions that will obviously prohibit successful prescribed burning. Only those days that met the following criteria were included in the data analysis:

1. Average relative humidity less than 70 percent over the 9 hours (Krueger and Pachence 1961).

2. No significant amounts of snow present on the ground.

3. Total precipitation less than a trace (.01 inch).

Other factors, such as excessive windspeeds or low temperatures, that would cause a day to be eliminated were accounted for in later analyses.

RESULTS

The average windspeed in Minnesota does not vary appreciably from 10:00 a.m. to 4:00 p.m. and remains nearly constant from 1:00 p.m. to 4:00 p.m. (Brown 1964). Our study shows there is little variation in the average 1:00 p.m. windspeed during the burning season (12 to 17 m.p.h.); however, April and May have the highest average windspeed and July and August have the lowest. Winds are more likely to exceed the allowable maximum in the spring; the windspeed will seldom exceed 20 m.p.h. during July and August (table 1).

Wind roses (see Appendix) for each month indicate that changes in the prevailing wind direction occur during the burning season. In addition, the conditions that make a day suitable for burning are not associated with any particular wind direction at any of the stations (fig. 1).

Radical changes in the wind direction during prescribed burning can cause serious problems. Consequently, burning should not be done under conditions that promote changes in wind direction. At the three stations, northeast winds are generally the most variable, northwest winds are the most persistent at Minneapolis and International Falls and southeast winds are most persistent at Duluth. Also, changes in wind direction are most likely when the windspeed is low (fig. 2).

The number of days since significant rain fall has occurred will influence the effect of a prescribed burn. Periods of long duration

[1] *Names and dates in parentheses refer to Literature Cited section.*

Table 1. — Probability of the windspeed being 15 m.p.h. or less and 20 m.p.h. or less on suitable burning days (1955-64).

Windspeed (m.p.h.)	April	May	June	July	Aug.	Sept.	Oct.	Nov.
MINNEAPOLIS								
15	0.52	0.59	0.68	0.77	0.85	0.71	0.72	0.67
20	.77	.80	.91	.96	.97	.91	.91	.86
DULUTH								
15	.52	.55	.71	.77	.77	.70	.68	.67
20	.76	.79	.88	.94	.95	.96	.88	.87
INTERNATIONAL FALLS								
15	.66	.69	.92	.94	.66	.86	.75	.74
20	.86	.88	.96	.97	.97	.96	.93	.93

without rain seldom occur in this region but lesser periods occur fairly frequently (table 2).

An attempt to determine the number of days that would be suitable for prescribed burning throughout the season must utilize some predefined limits for such variables as windspeed, temperature, etc. To do this, these important factors were standardized as follows:

Criteria for an acceptable burning day

1. Fine Fuel Spread Index, 15-35
2. Windspeed, 5-15 m.p.h.
3. Relative humidity, less than 70 percent
4. No snow on the ground
5. Less than a trace of rain (.01 inch)

On this basis, 25 to 40 burning days can be expected to occur each year (table 3). Most acceptable burning days occur during summer and early fall, particularly October.

DISCUSSION

These results provide useful information on the distribution and severity of the weather conditions in Minnesota. The averages presented here should not be used as accurate weather predictors but do indicate what can occur during normal or average years.

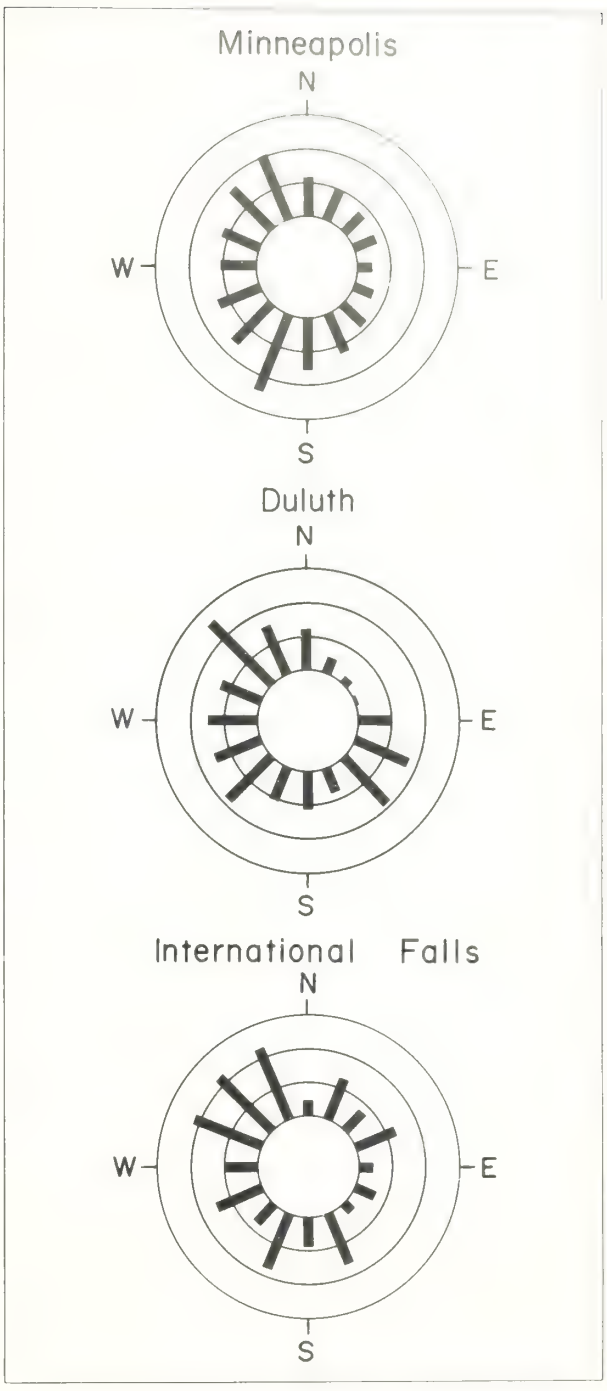

FIGURE 1. — Wind rose showing the percent of suitable days with a given wind direction. Note: each outside circle represents 5 percent.

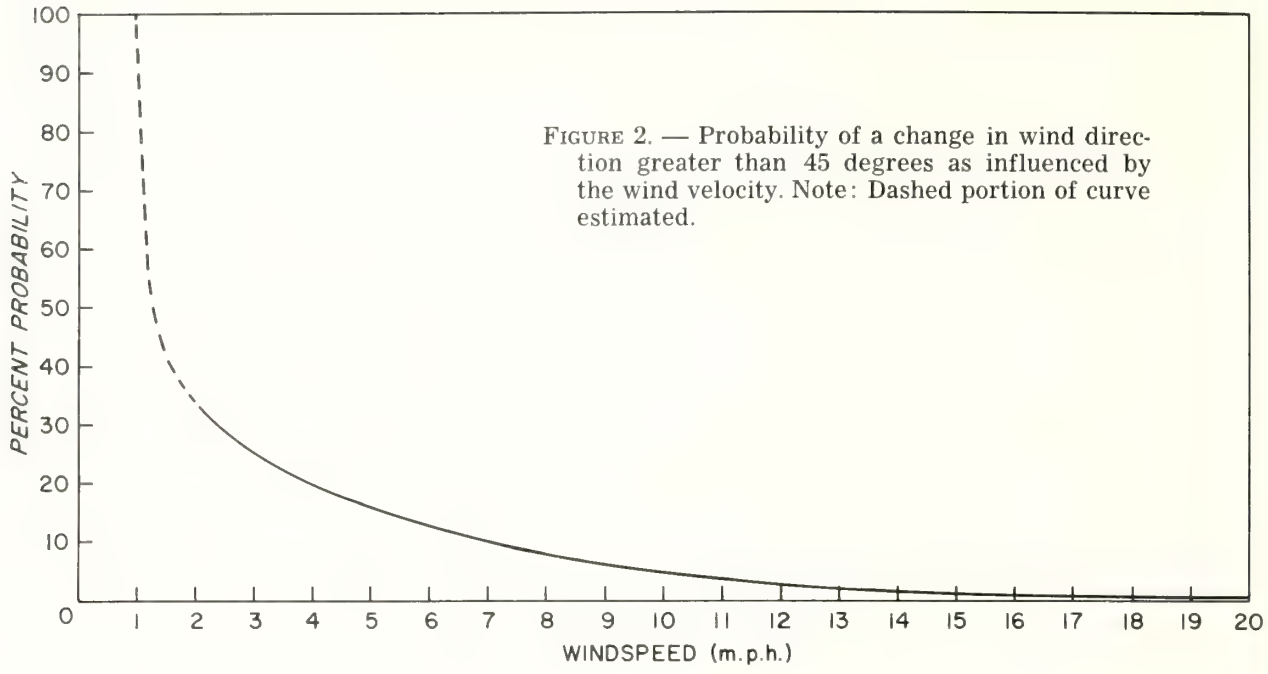

FIGURE 2. — Probability of a change in wind direction greater than 45 degrees as influenced by the wind velocity. Note: Dashed portion of curve estimated.

Rainfall distribution during the burning season is a key consideration in planning prescribed burning. The moisture content of the larger fuels is greatly influenced by precipitation and will determine to a large extent how the fire will behave and what the effects of the fire will be. Because fuel consumption depends on the moisture content of the fuel, Buildup Index may be used as the basic criterion for burning prescriptions (fig. 3). Other weather factors will largely be limited by the allowable safety and control standards.

CONCLUSIONS

Some conclusions about the weather patterns affecting a program of prescribed burning in Minnesota are:

1. Northwest winds are the most common winds on days suitable for prescribed burning.

2. The average windspeed that can be expected at 1:00 p.m. is highest during April and May and lowest during July and August.

3. Northeasterly winds are the most variable and northwesterly winds the most persistent.

4. Low-velocity winds (less than 8 m.p.h.) are much more likely to change direction than are high-velocity winds.

5. There is a 70-percent probability that the windspeed on suitable days will be less than 15 m.p.h. and a 90-percent probability it will be less than 20 m.p.h.

6. The probability of the occurrence of acceptable wind conditions is high, and unfavorable winds will generally not be the limiting factor in a successful burn.

7. From 25 to 40 acceptable burning days can be expected to occur in Minnesota each year; however, specific requirements may significantly reduce this number.

8. The months of July, August, and October are probably the best months for prescribed burning.

9. Suitable burning conditions occur most frequently in midsummer, and prescribed burning activity at this time will conflict the least with wildfire control activities.

Table 2. — Number of periods per year with X days since .1 inch of precipitation (1955-64).

Days since precipitation	Spring	Spring transition	Summer	Fall transition	Fall	Until [illegible]
MINNEAPOLIS						
0	11	4	46	5	6	2
1	7	3	26	4	3	24
2	5	2	19	3	3	12
3	4	1	14	3	2	13
4	2	1	9	2	2	10
5	1	1	7	2	1	13
6	1	1	5	1	1	9
7	1	*	3	1	1	6
8	1	*	2	1	1	3
9	1	0	1	1	1	3
10	1	0	1	1	*	2
DULUTH						
0	16	6	54	8	10	3
1	8	4	24	4	6	45
2	6	2	16	3	4	31
3	4	1	10	2	3	21
4	3	1	7	2	2	15
5	2	*	5	1	2	10
6	2	*	3	1	1	7
7	1	*	3	1	1	5
8	1	0	2	1	1	3
9	*	0	1	1	*	2
10	*	0	1	*	*	2
INTERNATIONAL FALLS						
0	14	5	45	8	9	31
1	7	3	22	4	6	43
2	5	2	15	3	4	30
3	4	1	11	2	3	22
4	3	1	7	2	2	16
5	2	1	5	1	2	11
6	1	*	4	1	1	7
7	1	*	2	1	1	5
8	1	*	1	1	1	3
9	1	*	1	1	*	3
10	1	*	1	*	*	2

*Less than 1.

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Table 3. — Suitable burning days per year by Buildup Index classes.
(In days per year)

Month	Buildup Index												
	5-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-150	Total
MINNEAPOLIS													
April	0.8	1.2	0.4	0.3	0.1	0.1	0	0	0	0	0	0	2.9
May	.6	.7	.6	.3	.2	.2	0	.1	.1	0	0	0	2.8
June	.2	.9	.3	.5	.3	.1	.1	.1	0	0	0	0	2.5
July	0	.4	1.1	.3	.3	.4	.1	.1	.1	.1	0	0	2.9
August	.2	.9	.7	.5	1.1	.4	.5	.1	.1	0	0	.1	4.6
September	.1	2.3	1.1	.4	.3	.2	.1	.1	0	0	0	0	4.6
October	0	.9	1.5	1.2	.9	.2	.6	.6	.3	.1	0	0	6.3
November	.1	1.1	.5	.3	.8	.4	.4	.3	0	0	0	0	3.9
Total	2.0	8.4	6.2	3.8	4.0	2.0	1.8	1.4	.6	.2	0	.1	30.5
DULUTH													
April	.4	1.0	0	.4	0	0	0	0	0	0	0	0	1.8
May	.1	0	.7	.5	.1	.1	0	0	0	0	0	0	1.5
June	.2	1.6	.5	.2	.1	0	.1	.2	0	0	0	0	2.9
July	.1	.8	1.1	1.1	.7	.1	.2	0	0	0	0	0	4.1
August	.1	1.3	1.3	.6	.5	0	0	.1	.2	0	0	0	4.1
September	.3	1.6	.9	.3	.2	0	0	0	0	0	0	0	3.3
October	.2	.7	1.5	1.4	1.2	.7	.5	0	0	0	0	0	6.2
November	.1	1.4	0	.2	.3	.2	.5	0	0	0	0	0	2.7
Total	1.5	8.4	6.0	4.7	3.1	1.1	1.3	.3	.2	0	0	0	26.6
INTERNATIONAL FALLS													
April	.6	1.9	.6	.1	.3	0	.2	0	0	0	0	0	3.7
May	.1	1.2	1.4	.4	.4	.2	.2	0	.1	0	0	0	4.0
June	.7	1.2	1.1	.1	.3	.2	.3	.2	.1	.1	.2	0	4.5
July	.1	2.1	1.6	.7	.6	.2	.2	0	0	0	0	.7	6.2
August	.1	1.4	1.6	1.9	.4	.4	.1	0	.1	0	0	0	6.0
September	.2	2.1	2.4	1.2	.3	.2	.1	0	0	0	0	0	6.5
October	.1	1.3	1.3	.9	.9	1.1	1.3	.6	0	0	0	0	7.5
November	0	.2	.4	.2	.1	.3	.6	.3	.3	0	0	0	2.4
Total	1.9	11.4	10.4	5.5	3.3	2.6	3.0	1.1	.6	.1	.2	.7	40.8

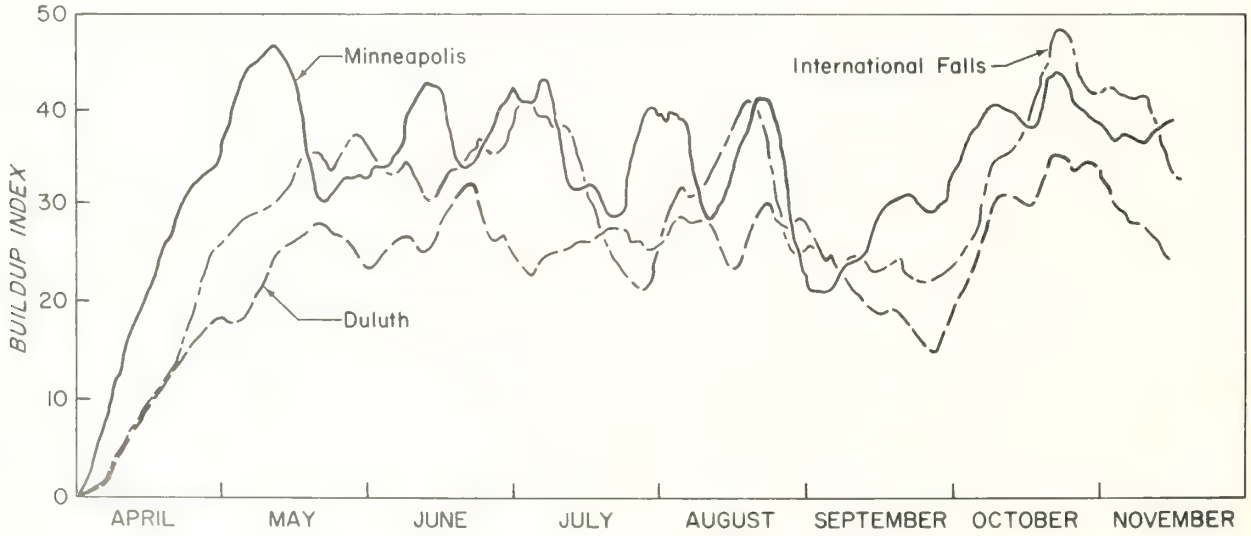
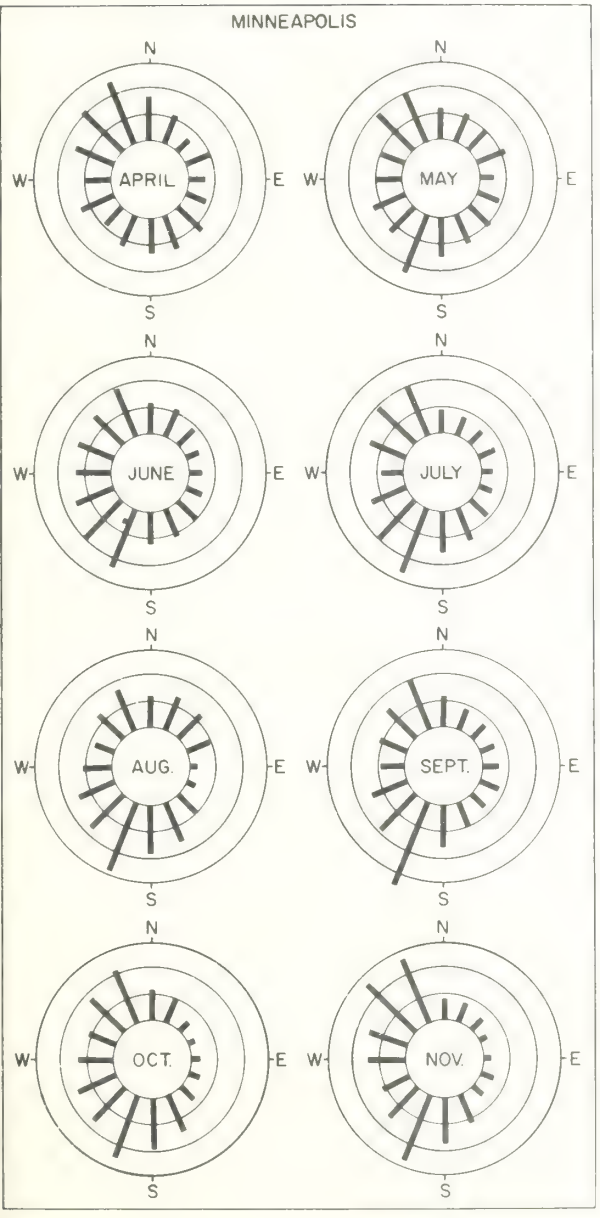
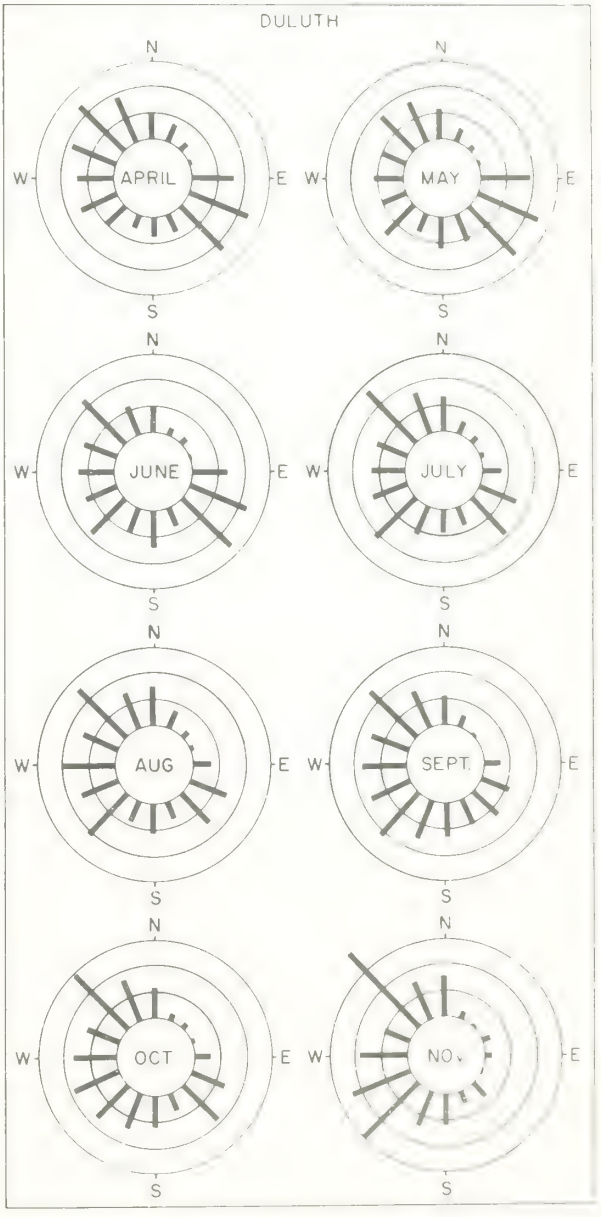


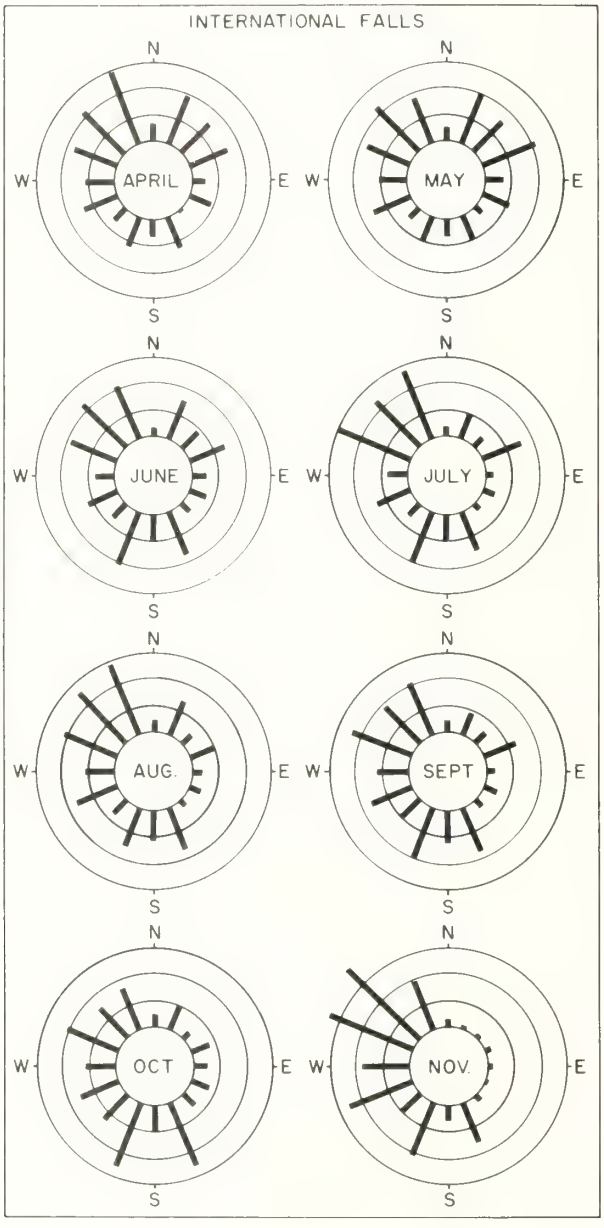
FIGURE 3. — Buildup Index trend over the season for Minneapolis, Duluth, and International Falls.

APPENDIX

Wind direction on suitable days by location and month, 1955-64
(Outside circles represent 5-percent intervals)






INTERNATIONAL FALLS
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SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

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1969

DURABLE RUSTIC WOODEN SIGNBOARDS

CLEMSON UNIVERSITY U.S.
OCT 20 196
S.L., TECH. & AGR. D.

Glenn A. Cooper

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

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Durable Rustic Wooden Signboards

Glenn A. Cooper

The need for rustic wooden signs at public nd private recreation sites has greatly in-reased since 1958. A growing population, a igher standard of living, increased leisure ime, and the ease of travel have provided op-ortunities for more outdoor recreation. On Vational Forest recreation sites alone there vere 279 million visits in 1960, and it is esti-nated there will be 700 million in 2000. This ncrease is making a tremendous impact on he estabishment of new recreation areas and he expansion and renovation of existing ones. All recreation sites, structures, roads, and rails that are being constructed or improved o meet the expected demand require signing or proper and safe use. Recreation site man-gers must plan for thousands of new road, rail, administrative, interpretive, and regu-atory signs that will be attractive, functional, nd durable.

Most recreation area signs are rustic in tyle and made of materials selected for their eauty, utility, and availability. Usually wood r wood-based materials are used, the letters re routed, and the boards are stained or nameled (fig. 1). Some rustic signs have art-vork. All exterior signs are subjected to the veathering of sun, rain, wind, and attacks rom decay organisms, insects, and vandals. Many of them must be refurbished or re-laced after only 2 years.

The increasing demand for signs, their elatively short life, and spiraling labor and naterial costs prompted us to investigate ways of minimizing sign costs. Federal, State, nd private sign shop procedures were tudied; also, many signboards and finishes vere tested in the laboratory and in four limatic areas of the United States. Then, rom these studies, guidelines were developed or wood signboard material selection to help reduce the processing and maintenance costs and increase the service life of rustic signs.

F-519066

FIGURE 1. — Medium density overlaid plywood is an excellent material for large signs. This 5- by 7-foot signboard has routed letters and is finished with brown and yellow enamels.

SELECTING SIGNBOARD MATERIAL

Manufacturing and field maintenance labor constitute the primary costs of a routed, wooden signboard. Often shop labor cost can be reduced by changing signboard materials. This has been accomplished in many cases by switching from edge-glued lumber to plywood for large signboards.[1] Changing to wood that holds finishes better has eliminated part of

[1] *American Plywood Association. U.S. Product Standard PS 1-66 for softwood plywood-construction and industrial. Reprod. Prod. Stand. Sec. Nat. Bur. Stand., 28 p., illus. 1966.*

the sign maintenance labor cost on federal recreation areas. These changes may mean higher material costs, but they usually result in less labor needed and lower total cost. Frequently, savings have been sought by buying inexpensive paints. But if a cheap paint fails in 2 years when a better one would last 4, it is obvious that the "savings" in original paint cost will be more than offset by the cost of refinishing.

Signboard Size and Shape

Most sign shops produce a variety of signboard sizes and shapes ranging from slat signs 4 by 12 inches to large recreation area entrance signs up to 8 by 12 feet. Slat signs up to 10 inches wide are easily made from standard widths of lumber. Larger signs can be made either by edge-gluing lumber to the desired width or by using plywood sheets. If a shop produces only slat signs, standard lumber that has good routing, finishing, and service characteristics is usually the best material. If many large signs are made, plywood is probably the best choice because labor is reduced and edge-gluing is eliminated.

Signboard size and material selection determine what shop facilities are needed. The shop manager must, therefore, know the sizes and shapes of signs he will produce and the facilities at his disposal before he can compare the total cost of production using either lumber or plywood. Usually, if orders for signs over 8 inches wide are anticipated, it is more economical to produce plywood signs than to produce lumber signs. Conversely, if only narrow slat signs will be produced, it is usually more economical to equip a shop to process dried and dressed lumber rather than plywood.

Slat sign production from lumber usually requires only crosscutting, routing, sanding, and finishing equipment. However, large edge-glued lumber signs require facilities and machines for clamping, planing, grooving, splining, and boring. In addition, planers and jointers require exhaust systems, and handling devices for the heavy signs are often needed. This equipment is expensive and may be utilized only part time. Furthermore, if rough green lumber is used, a dry kiln may be needed. If dressed, air-dried lumber is purchased, seasoning facilities may not be needed; but the cost of lumber in a large sign is then usually higher than plywood cost.

If plywood is used for large signs in lieu of lumber, less floor space is needed for carpentry work. Furthermore, large plywood signs can be efficiently produced with low-cost panel saws, portable electric 10-inch saws, sabre saws, sanders, and routers. If large signs are irregularly shaped, a medium density overlaid plywood is better than edge-glued lumber because layout can be done without regard to grain direction. The overlay hides the grain; sign blanks can be laid out with common edges for minimum sawing and maximum sheet utilization; material waste is reduced; and less room and labor for material storage and waste handling are required than if lumber were used.

Sign Use and Exposure

Signboard materials should have good finish-holding characteristics to minimize field refinishing and sign replacement costs. One exception to this principle occurs if signs are quickly destroyed by vandalism. There is no point in expending labor and materials for extended sign life if the expected life is only 1 year. However, many recreation signs are not extensively abused; and it usually pays to make such signs as durable as possible. For example, durable signs are economical in difficult access wilderness areas where sign replacement and maintenance costs would be excessive if frequent, long maintenance trips were necessary. In well patrolled areas where vandalism is minimized, durable signs are usually more economical than signs that last only one season.

Sign durability depends on the kind of construction material, how the sign is made and finished, and the severity of the environment. Solid wood material, plywood products and finishes vary greatly in durability, de

pending on the exposure conditions; and it is, therefore, important for sign manufacturers to know the exposure hazards and their effects.

Sunlight is detrimental to signs. Ultraviolet radiation degrades finishes and wood tissue. Intense and prolonged exposure to sunlight, such as occurs on south aspects and at high altitudes, will cause more rapid sign degradation than if the sign were on a north aspect or otherwise shielded (fig. 2). Protection by roofs and trees — especially conifers which provide continuous shade — prolongs sign life. Pigmented finishes are more sun resistant than most clear finishes.

Rain, snow, dew, and changing humidity cause moisture fluctuations that are damaging to wood and finishes. Windborne particles erode finishes. In some areas, atmospheric pollutants attack finishes. Warm, wet climates favor decay and insect attack. Sometimes woodpeckers, rodents, and game animals mutilate signs.

Sign location, the type of mounting, and exclosures can be used to resist the above hazards. But using durable materials is the first line of defense. For example, if decay is a serious hazard, as in the southeastern and Gulf States, naturally decay resistant or preservative-treated woods should be used. Where finishes erode quickly, erosion resistant paints or enamels and wood substrates that take and hold them well are more desirable than stains.

SELECTING SUBSTRATES

When the facts of sign production and exposure life are established, a manager can select a signboard if he knows the various signboard characteristics. Our laboratory and field exposure tests in four climatic areas were made to determine the routing and in-service performance characteristics of signboard materials finished with enamels, paints, stains, varnishes, and lacquers. These characteristics, plus information on moisture content, material grade, and wood grain charac-

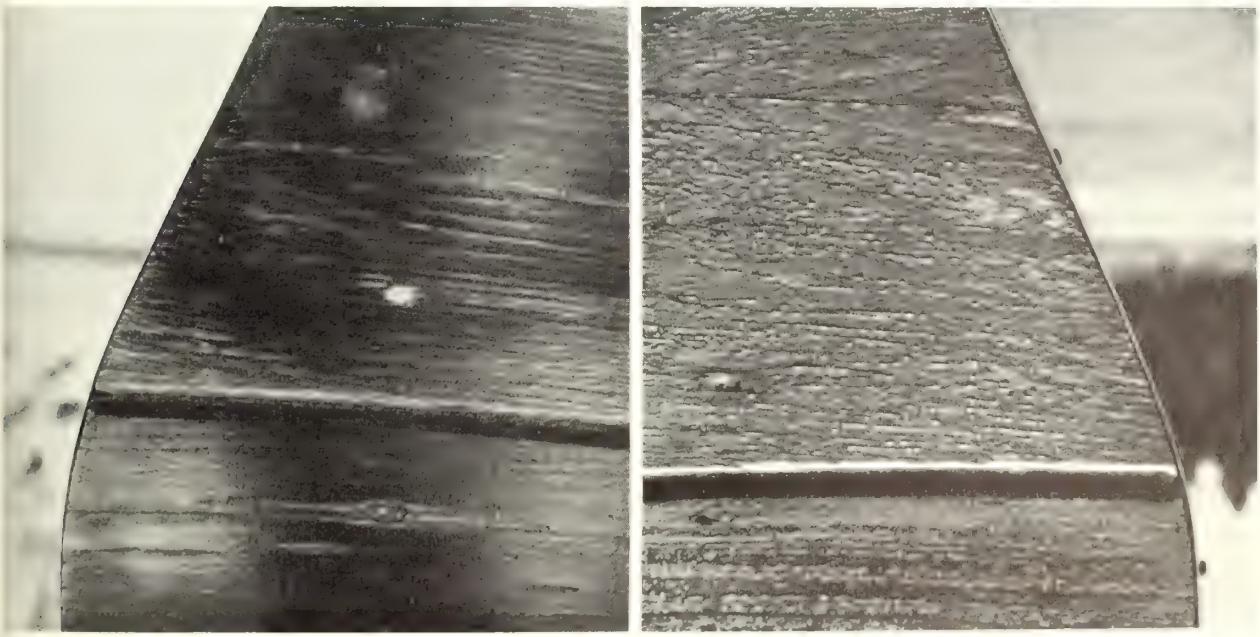

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FIGURE 2. — Left: North side of edge-glued redwood sign finished with a clear marine varnish. The varnish has yellowed but is intact. Right: South side of the same boards. The varnish has been broken down by intense sunlight; it is crumbling, peeling, eroding, and the wood substrate is a weathered gray.

teristics, are the facts sign builders need to consider when selecting materials.

Moisture Content

When wood is dried outdoors until it reaches an approximate equilibrium with the atmosphere, it is regarded as air-dry. The air-dry moisture content of wood may vary from 5 to 20 percent, depending on local climate. Air-dry wood will be relatively stable in outdoor use. Conversely, green wood will shrink in service causing warp, checks, splits, early finish failures, and a waste of labor and materials. Thus, to minimize drying degrade, signboard material should be air-seasoned to the average moisture content expected in service. For this reason many signbuilders keep their lumber stacked and stickered in unheated, well ventilated sheds. Signboards air-seasoned in one area may not be well suited for another area of different climate.

Grade

Both lumber and plywood vary in grade. The higher grades have fewer natural defects and cost more than the lower grades. The high grades of lumber will yield more, and larger, defect-free cuttings than the lower grades. However, for short slat signs, it is often more economical to use one of the lower grades of lumber and cut the short slats from the clear wood between defects. Also, some defects do not reduce the utility of a board for signs. When signboards are to be painted, naturally occurring stains in the wood are not objectionable. However, pitch pockets, bark pockets, the pith, knots, and splits should always be avoided.

Grain Orientation

Lumber signs should be made from vertical-grain boards. Flat-grain boards tend to develop loosened grain on the heart side. Loosened tips of summerwood bands eventually may shell from the board leaving a concavity, or they may feather out and give the slat a ragged appearance (fig. 3). However, the bark side of a flat-grain, planed board will not shell, splinter, and weather as fast as the heart side.[2] Some sign woods which tend to shell on the heart side of flat-grained boards are redwood, western redcedar, Douglas-fir, southern pine, and occasionally baldcypress and ponderosa pine.

F-519069

FIGURE 3. — Loosened summerwood bands on the heart side of this flat-grain redwood slat were evident after 1 year of exposure.

Vertical-grain lumber shrinks and swells less in width than flat-grain lumber. It does not twist, cup, surface check, or split as much as flat-grain lumber. Most importantly, vertical-grain lumber of many species holds finishes better than flat-grain lumber. All these advantages are particularly important when large signboards are made from edge-glued boards.

Some builders of edge-glued signs use flat-grain boards and alternate the pattern of the annual rings. This has the advantage of minimizing overall cup in glued-up flat-grain boards. But in this type of construction half of each sign face will be the heart side of the boards which may develop unsightly loosened grain.

[2] *U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Raised, loosened, torn, chipped, and fuzzy grain in lumber. U.S.D.A. Forest Serv. Res. Note FPL-099, 15 p., illus. Forest Prod. Lab., Madison, Wis. 1965.*

Differences Between Plywood Products and Lumber

Softwood plywood is made from Douglas-fir, southern pine, white pine, redwood, Sitka spruce, sugar pine, and ponderosa pine. Only Douglas-fir plywood was tested, but softwood plywood of other species, particularly if it has a medium density overlay, should not be excluded from consideration. Many hardwoods are also used in plywood construction, but their use is primarily for interior work. Hardwood plywood with clear face plies and exterior-type glue lines are usually too expensive for rustic signs. For this reason these were not tested, even though some may perform very well.

The sign-use characteristics of softwood plywood differ from lumber in the following respects:

1. Plywood panels have greater uniformity in strength than edge-glued lumber panels of equal length and width.

2. Plywood shrinks and swells less than lumber, and dimensional changes are about the same along the panel and across the panel.

3. Plywood has greater resistance to splitting than lumber, but it face- and end-checks more than flat-grain lumber of the same species.

4. Plywood has little tendency to warp, whereas poorly seasoned lumber and lumber without straight grain may warp badly in service.

5. Plywood veneers contain lathe checks that may open and cause finish failure where the end grain appears on all four signboard edges. Lathe checks are not present in lumber, but seasoning end checks are often present.

6. Most plywood face veneers are 3/32 or ⅛ inch thick and routing letters deeper than ⅛ inch results in excessive bit wear at the abrasive plywood glue line. Thicker face veneers, available on special order, eliminate glue-line routing.

7. Many plywood inner plies contain voids where they are split or not tightly butted. Lumber sometimes contains pitch and bark pockets, but they are usually not as frequent as voids in exterior grade plywood.

8. Most plywood is dried to about a 12-percent moisture content, whereas lumber can be purchased ranging from an 8-percent moisture content to the green condition.

9. Plywood is available from some manufacturers as precut sign blanks; often the manufacturers can also provide prefinished or custom overlaid blanks.

10. Commercial standards for softwood plywood, PS 1-66 (see footnote 1), are established by the trade, and several trade associations exist to certify adherence to standards. Panel sizes are standardized in the plywood industry. Lumber grading standards are established and lumber is sold by grade, but differing production practices among lumber manufacturers result in lumber size differences.

Characteristics of Various Woods and Plywood Products for Signs

Wood properties and performance characteristics differ among and within wood species. The wood properties of importance to signbuilders are: (1) the ease of routing and working the wood, (2) gluability, (3) natural durability or ease of preservative treatment, (4) finishing characteristics, (5) the occurrence of extractive stains and resins and their effect on finishes, (6) dimensional stability, and (7) resistance to checking and raised and loosened grain. The first three of these warrant special mention.

Signboards that do not rout easily should not be dismissed from selection. Some wood substrates that are difficult to rout without burring the edges are otherwise very suitable for signboards. The medium density resin-impregnated overlays on Douglas-fir plywood burr when routed and letter edges must be cleaned up by a light hand sanding. However, the medium density overlay plywood is excellent sign material. Similarly, basswood and soft maple sometimes do not rout cleanly, but they are relatively stable and hold finishes well. Conversely, the substrate in our tests

which routed best — hardboard on Douglas-fir plywood — delaminated after 1 year of exposure. Blackgum and red oak rout fairly well, but blackgum warps and red oak face- and end-checks excessively.

Natural durability should not be overrated when selecting signboard materials. The heartwood of redwood and western redcedar is very durable, but grain loosening and shelling in flat-grain boards may destroy the sign long before other less durable woods fail from insect attack or decay. Moreover, many nondurable woods can be treated with a 5-percent solution of water-repellent pentachlorophenol in light oil to eliminate decay and insect hazard; and the treated wood can still be stained or painted. Hardwoods, pines, and sap baldcypress used in the Southern States should be treated.

How easily woods glue should be considered whenever large signboards are made from lumber. As a rule, softer and more porous woods glue easier than the harder woods. However, all the woods that are otherwise suitable for signs are relatively light and porous and glue well. Moreover, other factors, such as gluing pressure, wood surface quality, wood moisture content, and the type of glue, are vital to a good bond and they can be controlled. Thus, with proper methods hard, low-porosity woods can be bonded successfully. Only waterproof adhesives should be used. Water-resistant adhesives are unsatisfactory for edge-glued signboards.

We tested 11 softwoods, 7 hardwoods, and 7 plywood products, each with several finishes, to determine which sign materials are most suitable. We used materials available in each region of the United States and made artificial weathering tests in the laboratory and then tested them in the field for 2 to 6 years. In addition, the experiences of sign-shop personnel and the results of their tests were tabulated.

Our findings (summarized in table 1) indicate what can generally be expected in sign production and exposure. Descriptions are derived from rigorous tests of flat-grain boards; vertical-grain boards will perform better. Severe exposures will cause earlier and more frequent failures than mild exposures. Improper seasoning, machining, assembly, and finishing methods will, too. However, because all materials were tested in the same manner, relative differences indicate the performance that can be expected in most situations.

Flat-Sawn Boards

Flat-grain, planed incense cedar, baldcypress, Alaska yellow cedar, and yellow-poplar performed the best. Flat-grain soft maple and basswood were not as good as the above species but were entirely satisfactory (table 1).

Other flat-grain woods were less satisfactory for several reasons. The pines exuded resins that lifted finishes, and they did not rout well (fig. 4). Flat-grain redwood and western redcedar developed loosened grain on the heart side (fig. 3) and both contained black extractives that leached onto and discolored the surface (fig. 5). However, vertical-grain redwood and western redcedar slats did not develop loosened grain and stained less than the flat-grain slats. Cottonwood burred extensively when routed (fig. 4) and was not dimensionally stable. Red alder and blackgum (fig. 6) were also unstable and developed many checks (table 1).

Plywood Products

Plywood slat signs were made and tested in the same manner as flat-grain boards. However, because we tested only Douglas-fir plywood constructed with different grades of veneer and with different overlays, each product is described separately in more detail than can be presented in a table.

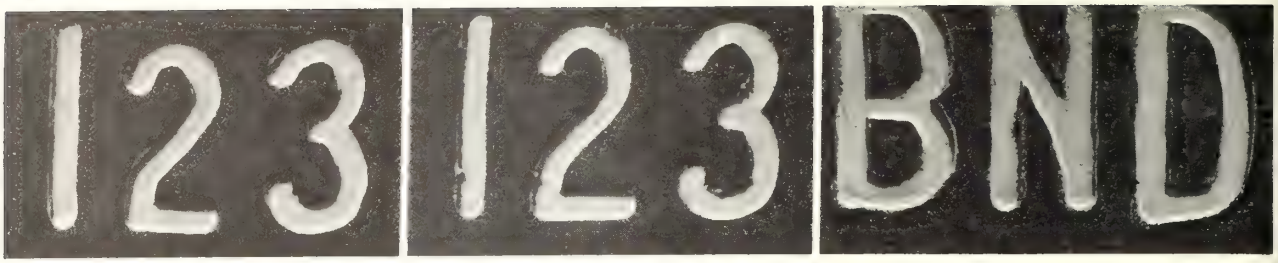
Exterior Douglas-fir Plywood

Exterior grade fir plywood with "A" grade veneer faces is available in widths to 60 inches and lengths to 144 inches. Other sizes with scarf joints are also available on special order. Fir plywood routs fairly well and takes

Table 1. — Characteristics of tested signboard wood materials for routed, rustic, flat-grained, slat signs

Material	Ease of routing	Ease of working	Ease of gluing	Natural durability	Ease of treating	Finish-holding ability	Extractive and resin bleedout[1]	Dimensional stability	Resistance to checking	Resistance to loosening of grain	Remarks	Overall rating for routed signs
SOFTWOOD LUMBER												
Sugar pine	Poor: burrs	Easy	Easy	Low	Moderate	Fair	Resin	Very good	Fair	Very high	Routs poorly, resin lifts finish	Not recommended
Northern white pine	Poor: burrs	Easy	Easy	Low	Moderate	Fair to good	Resin	Very good	Poor to fair	Very high	Routs poorly, resin lifts finish	Not recommended
Southern pine	Difficult	Difficult	Easy	Fair	Moderate	Poor	Resin	Fair	Poor	Very low	Routs poorly, resin lifts finish	Not recommended
Ponderosa pine	Poor: burrs	Easy	Easy	Low	Easy	Fair	Resin	Good	Poor	Moderate	Routs poorly, resin lifts finish	Not recommended
Sitka spruce	Poor: burrs	Easy	Very easy	Low	Difficult	Fair	None	Good	Fair	Very high	Routs poorly	Not recommended
Douglas-fir	Moderate	Difficult	Moderate	Fair	Very difficult	Poor	None	Fair	Poor to fair	Very low	Poor finish substrate	Not recommended
Coast redwood	Good	Fairly easy	Easy	Very high	2/	Very good[3]	Extractives: black	Very good	Fair	Very low	Bleedout, loosened grain	Vertical grain good[4]
Baldcypress	Excellent	Fairly difficult	Easy	Very high	Moderate	Very good	None	Good	Good	High	-	Good
Incense cedar	Good	Easy	Easy	Very high	2/	Very good	Extractives: slight	Very good	Good	Very high	-	Good
Western redcedar	Good	Easy	Easy	High	Very difficult	Very good[3]	Extractives: slight	Good	Good	Low	Bleedout, loosened grain	Vertical grain good[4]
Alaska yellow cedar	Excellent	Easy	Easy	Very high	2/	Very good	None	Good	Good	Very high	Limited availability	Good
HARDWOOD LUMBER												
Cottonwood	Poor: wools up	Difficult	Easy	Very low	Moderate	Poor	None	Poor	Poor	Very high	Routs very poorly	Not recommended
Red alder	Good	Easy	Easy	Low	2/	Good	None	Poor	Poor	Very high	Cups, checks	Not recommended
Red oak	Good	Fair	Moderate	Low	Easy	Fair	None	Poor	Poor	High	Excessive checking	Not recommended
Yellow-poplar	Excellent	Easy	Easy	Low	Difficult	Very good	None	Good	Good	Very high	-	Good
Soft maple	Moderate	Fairly easy	Moderate	Low	Moderate	Fair to good	None	Fair	Poor	Moderate	-	Fair
Basswood	Moderate: burrs	Easy	Easy	Low	Easy	Very good	None	Good	Good	Very high	-	Fair
Blackgum	Poor: burrs	Difficult	Difficult	Low	Easy	Very good	None	Poor	Poor	Very high	Twists frequently	Not recommended

1/ With oil stain finishes.
2/ No information
3/ Unless grain loosens.
4/ Flat-grain not recommended.



F-519070, 519071, 519072

FIGURE 4. — Flat-sawn, planed white pine (left) and ponderosa pine (center) burr slightly at the letter edges during letter routing. Loose fibers pick up paint and cause letter edges to appear ragged. Cottonwood (right) often wools up because it contains gelatinous wood fibers which do not cut cleanly.

stain and film-forming[3] finishes well. However, film-forming finishes crack on the exposed plywood edges due to the opening of lathe checks in the plies, and the finish fails earlier than on the faces. Douglas-fir plywood seldom develops loosened grain because the bark side of the face plies is always the face of the panel. Raised grain does develop, and finishes usually fail first over the raised, dense, summerwood bands. "B" grade inner plies in exterior grade plywood admit voids due to veneer splits and open butt joints between veneers in the same ply (see footnote 1). These voids are difficult to fill and finish if exposed by routing letters through the face plies of exterior plywood.

F-519073

FIGURE 5. — This redwood slat with one coating of a water repellent cedar color stain finish was discolored by dark extractives leaching to the surface after 21 months of exposure with less than 20 inches of rainfall.

[3] *Film-forming finishes do not penetrate the wood. We tested paints, enamels, lacquers, and varnishes.*

F-519074, 519075

FIGURE 6. — Unstable woods check and warp when subjected to cycling moisture conditions. Red alder (left) developed numerous end checks. Blackgum (right) twisted badly due to interlocked grain developing uneven stresses while cycling.

Interior grade fir plywood should never be used for outdoor signs as the glue line is not waterproof and the plies will delaminate in a hot, wet exposure. Exterior fir plywood has a waterproof glue line that will not delaminate if it is properly made.

Marine Douglas-fir Plywood

Marine grade plywood differs from exterior plywood primarily in the grade of the inner plies. Marine plywood has solid (one piece) "B" grade veneer inner plies without voids. In other respects marine plywood is similar in performance and characteristics to exterior plywood. Where large signboards are desired with stained finishes that show the grain, this plywood makes a good substrate (fig. 7).

F-519076

FIGURE 7. — This Douglas-fir marine plywood sign has held its water-repellent stain well for 4 years. Raised grain and dense summerwood bands would have caused early failure if film-like coatings were used.

Medium Density Overlaid Fir Plywood

Medium density overlays are resin impregnated cellulose fiber sheets containing about 20-percent (by weight) thermosetting phenol- or melamine-type resins (see footnote 1). The medium density overlay is bonded to the faces of exterior Douglas-fir plywood. This product is designed specifically for painted signs (fig. 1). The overlay is opaque, it masks face veneer patches and the grain pattern, and it overcomes checking. When routed, the overlay burrs and it must be sanded smooth before finishing. The overlay takes and holds stains, paints, and enamels well, usually holding longer than the best bare wood substrate. If unfinished, the overlay will turn gray. Where large opaque-finished signboards are desired, this is one of the most suitable materials available.

High Density Overlaid Fir Plywood

This overlay is made of cellulose fiber sheets impregnated with phenol or melamine thermosetting resins not less than 40 percent by weight (see footnote 1). This overlay is usually a natural translucent color, but is also available in several colors depending on the manufacturer. The overlay is on exterior grade Douglas-fir plywood, and it is not intended for painting. Reflective sign sheeting can be directly applied to it, but it must be cleaned with steel wool and a solvent before applying enamel. The high density overlay is difficult to rout, it tends to chip, and is very abrasive on router bits. However, it is an excellent substrate for reflective sheeting overlaid signs that are not routed.

Acrylic Overlaid Fir Plywood

Acrylic overlays are cellulose fiber sheets containing thermoplastic resins pigmented with waterproof colors. They are similar to the medium density overlay and are available in at least four colors — green, red, blue, and white. We tested specially prepared brown overlays on exterior Douglas-fir plywood and found they weathered well with fairly good color stability. Routing and edge checking characteristics were the same as the standard medium density overlay. If finishing is required on this overlay, the surface should be cleaned with steel wool and a solvent, such as xylol. If the desired sign colors are available, this is a good material for large signboards.

Plastic Overlaid Fir Plywood

Exterior Douglas-fir plywood with a polyvinyl fluoride plastic sheet overlay is available in many colors from several manufacturers. The plastic overlay has excellent color stability and is very durable. The plywood edges check as in exterior fir plywood. The greatest disadvantage of this material is its routing characteristics. The polyvinyl fluoride overlay does not cut; it tears, flaps aside, and leaves a ragged, feathered edge when routed with conventional core box bits. This is due to the lack of rigidity in the film. We found this could be overcome by using down-cutting, spiral flute routing bits. However, the bits must be newly sharpened and they will only rout 400 to 600 lineal inches before resharpening is needed. The film can be painted after it has weathered for a year, or immediately if the purchaser specifies adherable surfaces.

Hardboard Overlaid Fir Plywood

Standard or tempered hardboard faced fir plywood panels with and without polyvinylfluoride plastic overlays were tested artificially and in field exposures. The hardboard routs well and is well suited to take and hold paints. However, none of the products tested was waterproof, a prime requisite for signs. The hardboard swelled and eventually began to separate near the plywood-hardboard glue line. Plastic overlays did not enhance signboard life because the hardboard edges were exposed, and the plastic overlays were permeable to moisture.

These products were manufactured for interior use and were not designed by the manufacturer for exterior use. Before our tests we were warned that the product was not waterproof, and our tests in no way reflect on the quality of the product for its intended use.

SELECTING FINISHES

Signboards are finished for two reasons: to give the surface the desired appearance and to protect the wood from weathering. Thus, finish selection involves color, gloss, and the impression the sign is meant to convey to the viewer. Rustic signs are usually shades of brown or green that blend with the scenery but are plainly visible through the use of contrasting or reflective letter paints.

Finishes protect the wood from weathering by keeping the moisture content of the wood reasonably uniform, particularly near the surface. This reduces the tendency of the wood to shrink and swell and subsequently check and split. Pigmented finishes also provide the wood protection from the sun's ultraviolet rays.

How well finishes perform depends on several factors: the kind of wood used, the type of finish used, and how the finish is applied.

Kind of Wood

In the first year of sign exposure the kind of wood used for a finish substrate has comparatively little effect on the performance of the finish. If failures occur the first year, it is more likely due to the type and composition of the finish. But once a finish begins to deteriorate due to embrittlement, the kind of wood substrate determines subsequent finish behavior.[4]

How well coatings perform on softwoods depends on several factors. One of the most important is the amount and distribution of the summerwood, because summerwood provides poorer anchorage for coatings than springwood. Thus, on flat-grain boards with wide summerwood bands, as in Douglas-fir and southern pine, embrittled paint fails earlier than on other flat-grained softwoods (such as the white pines) that do not have dense, wide summerwood bands. The effect of dense summerwood bands is reduced if vertical-grain boards are used because the summerwood bands are narrowest on the faces of such boards, other factors remaining equal. Furthermore, using vertical-grain boards avoids the problem of finishing the heart side of dense softwoods that often develop loosened grain. Redwood and western redcedar vertical-grain slats perform well as finish substrates.

Softwood resins and extractives may also affect finishes. Resin bleedout may lift finishes, discolor them, or have a harmful chemical effect on lead and zinc paints. Extractives in redwood and western redcedar may leach out and discolor surfaces finished with stains or emulsion paints (fig. 5), but extractives often improve the durability of linseed oil paints.

As in the softwoods, the lighter hardwoods hold coatings longer than the dense hardwoods. Furthermore, hardwoods with fine pores hold coatings better than hardwoods that have large pores. For this reason, it is often necessary to apply a filler to large-pored hardwoods so coatings can bridge the pores.

[4] *Browne, F. L. Wood properties and paint durability. U.S. Dep. Agr. Misc. Public. 629, 10 p., illus. 1962.*

Kind of Finish

Several finishes are commonly used on signs. These can be classified as opaque or transparent. Coatings containing pigments are opaque and include enamels and paints. Examples of transparent finishes are varnishes, clear lacquers, and shellac.

Enamel

Enamels are natural or synthetic varnishes or lacquers to which opaque pigments have been added. Varnish enamels are usually the most durable finishes. Pigmented nitro-cellulose lacquers are brittle and not durable (fig. 8). Varnish-base enamels form smooth, tough, elastic films with better wearing properties than paints and transparent finishes (fig. 1). Furthermore, enamels dry faster than oil paints. However, enamels differ greatly in their properties according to their formulation. What may appear on the market as two identical finishes by different manufacturers will, in fact, be quite different in their performance characteristics. We tested several enamels: some were the most durable finishes tested and lasted 6 years without failure; others were less durable than the best paints we used. Coincidently, the best enamels were the most expensive.

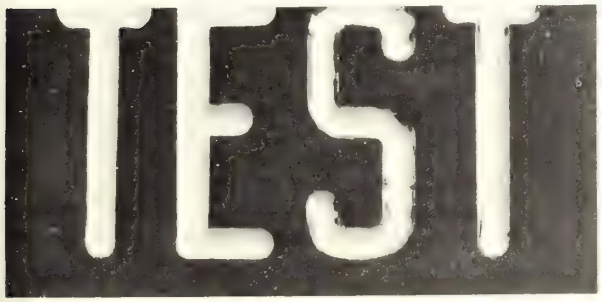


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FIGURE 8. — Puddled yellow lacquer failed after 2 years of exposure. The letters TE were primed and are cracked; the letters ST were not primed and the lacquer has peeled away.

Paints

Paints consist of finely ground pigments in a liquid vehicle. Two general types are in widespread use on signs: oil paints and emulsion paints. In oil paints the vehicle is a mixture of oil and resin and a volatile thinner, such as turpentine. When the oil paints dry, the vehicle binds the pigments together in a uniform tight film that has relatively low water permeability. In emulsion paints, made by combining pigments with resin particles dispersed in water, the water evaporates leaving the particles of pigments surrounded by resin in a film that is not usually as uniform or as tight as oil paint films. Thus, water vapor generally passes through emulsion paints more readily than through oil paints, and water vapor blistering may be greatly reduced. Such emulsion paints are sometimes called exterior latex or water-base paints.

The most widely used emulsion paints for signs are the acrylic resin and vinyl resin types. Both types usually dry faster, are more fade resistant, and spread easier than oil paints. However, the emulsion paints may require more coats to build up the same thickness as an oil paint; and they can be stained by extractives (see footnote 4). We found that some exterior emulsion paints are very durable and some are almost useless. Furthermore, emulsion paint durability depends on how long the film has cured before it is exposed to rain. An emulsion we exposed 5 days after application was nondurable, whereas the same emulsion on the same substrate was very durable when it cured 4 weeks before exposure.

Oil paints varied less in performance characteristics than the emulsion paints. If properly applied, the oil paints (linseed oil, soya oil, or fish oil vehicles) will last more than 3 years without failures on wood signs. Oil paints designed primarily for use on metal should not be overlooked. One of the most durable paints we tested was a two-coat system of paint for metal (fig. 9). Some house paints of the chalking type have good dur-

ability, but they fade when pigmented, and chalk runoff often discolors the lower parts of a sign.

F-519078

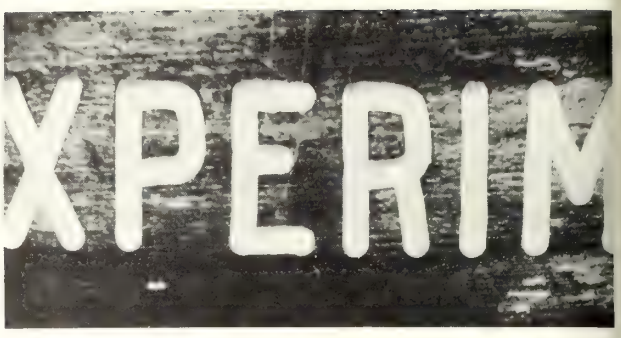
FIGURE 9. — Brown metal paint and yellow reflectorized letter enamel on this baldcypress slat had no failures after 2 years at a severe Gulf Coast site exposed to two hurricanes and frequent cycles of rain and hot sun.

Semi-Opaque Pigmented Stains

We also tested the semi-opaque pigmented stains that differ from paints in that they do not form a film but penetrate the wood. These stains consist of ground pigments in an oil vehicle with some drying oil or varnish and relatively large amounts of coal tar or petroleum solvents.[5] These stains do not raise the grain, and the colors are fairly light resistant. Furthermore, pigmented oil stains that penetrate wood surfaces do not blister, crack, or peel. They are very durable on rough-sawn lumber, but on planed surfaces of signs they erode in about 4 years (fig. 10). However, stain finishes are easily refurbished. Often a roller-applied coat of boiled linseed oil will brighten a stain that has not lost its pigmentation.

Varnishes

This type of transparent finish includes many formulations composed of plant or synthetic resins, with drying oils, volatile thinners, driers, and plasticizing ingredients. The film properties depend largely on the proportions of each ingredient and the type of resin used. These varnishes dry by evaporation and oxidation or by resin polymerization.



F-519079

FIGURE 10. — After 4 years of exposure, this yellow-poplar sign slat is in good shape, but the water repellent stain has eroded and exposed the bare wood. This can be easily refurbished and be more durable than originally. Paints and enamels last longer on yellow-poplar but are more difficult to refurbish than stains.

Transparent finishes on signs are usually not satisfactory. Ultraviolet radiation causes photochemical degradation of the finishes and of the wood fibers holding the finish (fig. 2). We tested epoxies, polyesters, "marine" and other varnishes and none was entirely satisfactory. They checked, cracked, curled, flaked, and peeled after 2 years of exposure and were almost gone after 6 years (fig. 11).

Lacquers

Clear lacquers composed of resins and cellulose esters, usually nitrocellulose, solvents, and plasticizers, are rapid drying. However, the lacquer film is brittle and dimensional changes in the substrate often rupture the film. If lacquer is puddled too thickly in routed letters, a dry film forms over the top before the bottom portions have dried. Because lacquer dries by vaporization of the solvents, the vapors are trapped beneath the top film until they bubble and rupture the film. These bubbles leave an unsightly crater in the film and form weak spots that fail quick-

[5] *U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Forest Products Laboratory natural finish. U.S.D.A. Forest Serv. Res. Note FPL-046, 5 p. Forest Prod. Lab., Madison. 1964.*

ly. Clear lacquers are not durable on signs and usually begin to fail in less than 1 year. They are ruptured by dimensional changes in the substrate, and they break down quickly from ultraviolet light radiation.

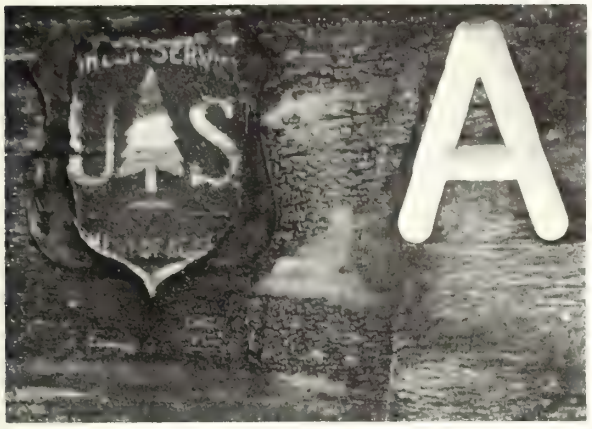


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FIGURE 11. — This redwood sign was finished with a two-part epoxy resin clear finish advertised as the most durable finish available. It failed after 2 years due to ultraviolet light degradation. What finish is left after 6 years is badly cracked, curled, and peeled and can be brushed away. Note failure of the decal.

How the Finish Is Applied

Assume that a sign manufacturer is making routed rustic signs and has decided to use vertical-grain incense cedar for slat signs and medium density overlaid plywood for large signs. Both types of signs will be finished with a yellow enamel for the routed letters and a brown enamel for the background. What is the best way to apply the finish?

Three procedures are in wide use and each has its advantages and disadvantages:

Procedure 1 (recommended method).

a. Rout the letters in the unfinished signboard.
b. Wire brush the routed channels to remove loose fibers and sand any burred edges.
c. Spray the entire signboard and letter channels with a primer that is suitable for both the letter and background enamel.
d. Spray the routed area with the finish letter coat using a mask to limit letter enamel on the background but not between letters.
e. Roll on the background enamel with a short nap roller squeezed fairly dry to avoid running enamel into letters.

Procedure 2.

a. Spray or roll on the background enamel primer and one or two top coats.
b. Rout the letter channels.
c. Puddle in the letter enamel primer from an oilcan or squeeze bottle.
d. Puddle in the letter enamel top coat.

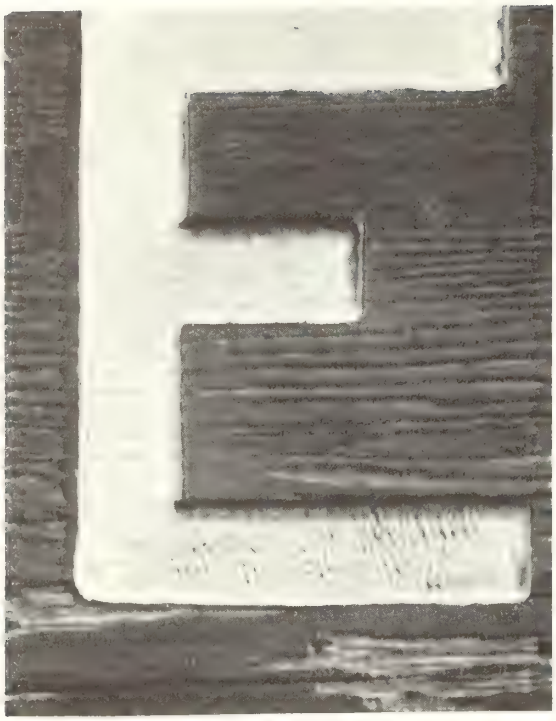
Procedure 3.

a. Same as steps a and b in Procedure 1.
b. Puddle in the letter primer and top coats.
c. Roll on the background enamel primer and one or two top coats.

Procedure 1 is the best method for the following reasons: Spraying of letter enamels is usually better than puddling because more even coats can be applied by spray. Puddling (Procedures 2 and 3) requires little skill but results in a coating that is too thin on the sides of the routed letter channels and too thick in the channel bottom. This usually results in early failures (figs. 12, 13, and 14).

Both the prime and top coats of the letters are continuous coatings, whereas, in Procedures 2 and 3 the puddled letter finishes have no continuity between letters and do not cover any areas also covered by the background finish. Thus, there often is an area of the routed letter edge which receives little finish and leads to early failure of both letter and background finishes.

Some sign builders try to take shortcuts in sign finishing. One most frequently used is the one-coat system. Even the best paints and enamels perform poorly if they are not applied over a primer (figs. 15 and 16). One thin coat wears out early, and one thick coat



F-519081

FIGURE 12. — A linseed oil house paint dried with a wrinkled surface because it was puddled too heavily in one coat.

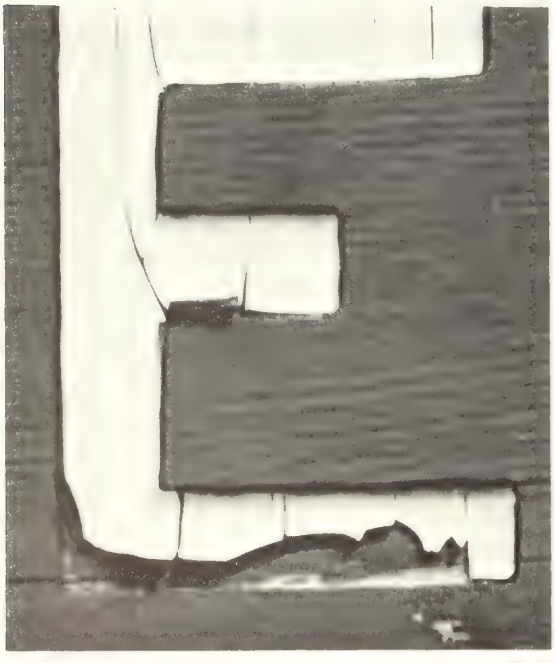


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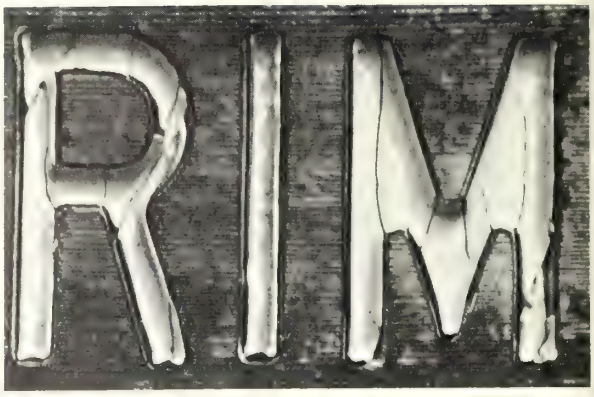
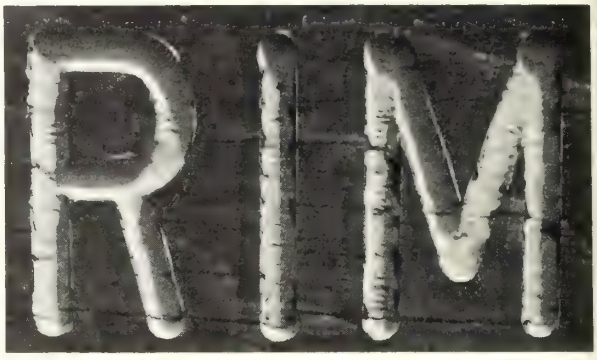
FIGURE 13. — Cross grain cracking of house paint puddled in letter channels resulted in sign failure after 2 years.



F-519083

FIGURE 14. — This alkyd resin enamel is durable, but a single thick application destroyed its durability. The letters were unsuitable after 18 months of exposure.



F-519084

FIGURE 15. — A ponderosa pine slat with a single application of yellow reflective coating brushed into the letter channels — 4 years of southern exposure caused flaking and failure (see fig. 16).

F-519085

FIGURE 16. — A ponderosa pine slat with priming before finishing with yellow reflective coating — same exposure as slat in figure 15. This finish is in excellent condition after 4 years of exposure.

cracks too soon and later scales. If coatings are sprayed so that the total thickness is 5 mils (5 thousandths of an inch) with a two-coat system (primer plus one top coat), they usually perform quite well. A three-coat system, i.e., primer and two top coats, is usually better but requires additional labor.

Another faulty shortcut is to stretch finish coverage by the addition of inexpensive vehicle fluid, usually linseed oil, or solvents. This increases greatly the chance of the paint wrinkling as it dries. Usually the additions are unnecessary because high-quality paints and enamels are sold ready to apply except for stirring. Only recommended thinners should be added as necessary for proper flow, and they should be added according to the manufacturer's recommendations.

A SUMMARY OF GUIDELINES

The following recommendations are based on established wood properties, artificial weathering tests, and field exposure tests in four climatic regions of the United States. These materials are not the only ones which will serve well for signs, but they are the best of those we tested. Species availability within each region has been considered.

For large signs, regardless of geographic location, the best material is medium density overlaid Douglas-fir plywood.

For slat signs, recommended materials vary with location:

Region	*Recommended species*
Pacific Northwest	Vertical-grain incense cedar Alaska yellow cedar, redwood, or western redcedar
Lake States and Northeast	Basswood or soft maple if incense cedar is not available
Southeast	Baldcypress or yellow-poplar
Southwest and dry Western States	Vertical-grain incense cedar, redwood, or western redcedar

Softwood slat signs should be clear, heart, vertical-grain boards, not over 8 inches wide, and seasoned to the moisture content they would be expected to average in service. Basswood and soft maple perform fairly well flat-grained, need not be heartwood, and can be economically made from No. 1 Common lumber. However, hardwoods should be treated with a water repellent preservative to help prime the wood and prevent decay. Plywood with medium density overlays should have solid "B" grade veneer first and inner plies without splits and voids. If possible, first plies should be 5/32-inch thick so that letters can be routed to a depth of ⅛ inch without going through the first ply.

These woods should give at least 4 years of service if high-quality enamels with good priming are spray- or roller-applied. Some emulsion paints will not dry quickly and may fail early in wet climates. Lacquers are brittle and fail early, and clear coatings break down sooner than pigmented coatings in sunlight. Where a rustic appearance is desired, a pigmented water-repellent stain applied to rough sawn, vertical-grain redwood or western redcedar gives excellent results. It is easily applied, and after some weathering a second coat can be rolled on that is more durable than the first. Every finish varies according to the manufacturer and should be tested and judged on its own merits on the intended substrate and in the environment where it must serve.

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Timber Management Guide for Shortleaf Pine and Oak-Pine Types in Missouri, by K. A. Brinkman and N. F. Rogers. U.S.D.A. Forest Serv. Res. Pap. NC-19, 15 p., illus., 1967.

Selection of Superior Yellow Birch Trees, A Preliminary Guide. by Knud E. Clausen and Richard M. Godman. U.S.D.A. Forest Serv. Res. Pap. NC-20, 10 p., illus., 1967.

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Prescribed Burning Weather in Minnesota, by Rodney W. Sando, U.S.D.A. Forest Serv. Res. Pap. NC-28, 8 p., illus. 1969.

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

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the MARKET FOR WOOD PICNIC STRUCTURES

Jerry A. Sesco

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT of AGRICULTURE

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NOTE: The author is Associate Market Analyst, North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service, headquartered at the Station's field office in Carbondale, Illinois, which is maintained in cooperation with Southern Illinois University.

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The Market for Wood Picnic Structures

Jerry A. Sesco

Outdoor recreation is increasing in the United States. There are no indications of a slowdown; by the year 2000 our population should double and the demand for recreation should triple.[1]

This increasing demand has brought about extensive plans for the development, expansion, and rehabilitation of outdoor recreation areas and facilities (fig. 1). Long-range plans call for increasing picnic facilities nearly threefold and camping facilities about ninefold.[2] For example, National Forests alone will develop or rehabilitate 30,000 recreation sites containing 300,000 family camp and picnic units by 1972.[3]

FIGURE 1. — Many new structures are being constructed on outdoor recreation areas. (F-518740)

[1] *Outdoor Recreation Resources Review Commission. Outdoor recreation for America. p. 25 Washington: Government Printing Office. 1962.*

[2] Ibid., *p. 53.*

[3] *U.S.D.A. Forest Service. Development program for the National Forests. U.S. Dep. Agr. Misc. Pub. 896, p. 13. Washington: Government Printing Office. 1961.*

Some further evidence of the recent growth of the overall market for outdoor recreation is found in Bureau of Census data: between 1954 and 1963, the value of shipments of wood and metal porch, lawn, and outdoor furniture increased from $68.4 million annually to $118.1 million annually — an increase of 73 percent.[4]

Manufacturers of quality wood products can profit by the growth in demand for outdoor recreation. They will be in a better position to increase their markets, however, if they know how purchases are made, who the purchasers are, and where they are located.

This report describes the public market for picnic structures, the relative importance of the various market segments, and the current and expected trends in demand for six north-central States. Picnic structures include picnic tables, shelters, benches, and sanitary facilities.

STUDY METHODS

Definitions

For the purpose of this report, an outdoor recreation area is defined as a publicly owned and managed land and water area used for recreational purposes. Examples are public forests, parks, roadside areas, and wildlife refuges. Privately owned and managed recreation areas were not included in the study.

[4] *U.S. Bureau of the Census. Census of Manufacturers: 1963. Volume II, Industry Statistics, Part 1, Major Groups 20 to 28. p. 25A-19. Washington: Government Printing Office. 1966.*

The jurisdiction of the recreation agencies included in the study are self-explanatory except perhaps for "municipal" and "metropolitan" park agencies. Municipal recreation agencies usually administer recreation areas within a city's limits. Metropolitan recreation agencies, on the other hand, administer areas in a larger territory that may include one or more counties and municipalities.

The Study Area

The States of Illinois, Indiana, Iowa, Kentucky, Missouri, and Ohio were selected for the study. In 1960 these States had 19 percent of the Nation's population and about the same percentage of the Nation's public recreation acreage. Due to its expected economic growth in the next few decades, the study area offers a large potential market for outdoor recreation structures.

The Sample

In 1965 questionnaires were sent to the U.S.D.A. Forest Service; U.S.D.I. Fish and Wildlife Service; U.S. Army Corps of Engineers; State park, forestry, highway, and fish and game headquarters; all municipalities of more than 25,000 population; and about 12 percent of those municipalities with populations from 2,500 to 25,000.

NUMBER AND TYPE OF OUTDOOR RECREATION AREAS

The market for recreation area structures is indicated by the location, number, and types of recreation areas that exist.

Most of the public recreation areas in the six States are in the southern half of the region. Federally owned areas, amounting to over 3 million acres or about 68 percent of the total, are comprised primarily of land administered by the Forest Service and the Corps of Engineers. Missouri has the largest amount of Federal recreation acreage with more than 1½ million acres. Camping, picnicking, hunting, fishing, swimming, and boating facilities are available on many of these acres.

There are 276 State parks in the six states containing more than 310,000 acres. These parks range from 10 acres to 15,000 acres in size and are more evenly distributed throughout the six States than Federally owned areas. Iowa has the largest number of parks with 77, while Ohio has the greatest State park area with 86,000 acres.

State agencies administer about 850,000 acres that are available for fishing, hunting, and camping. State-owned forest land is mostly in the southern half of the six States; fishing and hunting areas are more evenly distributed. Missouri has the largest acreage in State-owned fish, game, and forest areas.

State highway agencies administer about 1,350 roadside areas that contain more than 2,000 acres. Most of these areas, which average 1 to 2 acres in size, have one or two picnic tables; many of the larger areas have toilet facilities. Illinois, Ohio, and Kentucky account for most of the roadside areas in the six States.

There are many historic sites, monuments, shrines, camps, beaches, and public access areas administered by State agencies in the study area. Most of these areas contain less than 10 acres each.

In addition to Federal and State areas, there are about 248,000 acres of city, county, and metropolitan park land in the six States. Ohio and Illinois account for more than half the total acreage. Generally, these areas receive more intensive use than Federal and State recreation land.

RECREATION STRUCTURES

There are many types and designs of outdoor recreation structures in the study area. This report considers the types most frequently found on picnic and camping grounds. Structures discussed include picnic tables, shelters, benches, toilet facilities, and information and concession buildings.

Picnic Tables

More than 200,000 picnic tables were in use on all publicly owned recreation areas in the six States.

Most of the picnic tables reported by Federal agencies were on areas owned by the Corps of Engineers, followed by the Forest Service, Fish and Wildlife Service, and the National Park Service. Most of the picnic tables on State land were in the State parks, followed by highway roadside areas, State forests, and State fishing and hunting areas.

Of the total number of tables reported, county, metropolitan, and municipal recreation areas collectively accounted for 60 percent. Most of the areas administered by these agencies are relatively small compared to State and Federal areas, but they are generally subject to more intensive use.

Type of Construction

Based on construction materials used, there are four major types of picnic tables: all wood, all concrete, combination wood and concrete, and combination wood and metal. Less frequently used types are: all metal, combination fiberglass and metal, and combination metal and fiberglass overlaid wood.

Tables made completely of wood were the most common type in the study area, accounting for 162,000 or 81 percent of the tables reported by respondents (fig. 2). Combination wood and metal tables ranked second with 15 percent of the total. Concrete and "other" types accounted for about 3 percent of the total. Combination wood and concrete tables made up less than 1 percent of the total.

Wood Use

The volume of lumber used in a single picnic table ranges from around 40 net board feet for a 6-foot combination wood and metal table to about 100 net board feet for an all-wood table. However, in the aggregate, picnic tables require millions of board feet of lumber. For instance, the estimated 162,000 all-wood tables in the study area required 16.2 million board feet of lumber.

FIGURE 2. — All-wood tables were the most common type found. (F-518741)

It is apparent that wood is the most important component in picnic tables, being used to some extent in about 95 percent of the tables reported.

Softwoods, primarily Douglas fir, were most often used in picnic tables; however, a few tables were constructed of hardwood lumber. Where both types of lumber were used in the same table, hardwood lumber was most often used in the legs and braces and softwood lumber in the tops and seats.

Several different sizes of picnic tables were used, but some sizes were more common than others. The most common table lengths were 6, 7, and 8 feet. The most common table top widths were 30, 33, and 36 inches. Most of the tables used 2-inch-thick lumber ranging from 4 to 12 inches in width, depending on the table design.

Service Life and Reasons for Repair or Replacement

The service life and need for repair of picnic tables vary greatly and depend primarily upon frequency and intensity of use, frequency and methods of maintenance, type of material used, exposure to weather, preservative treatment, and protective finish.

Estimates of serviceable life averaged 10 years for wood tables, 13 years for wood and metal tables, 15 years for wood and concrete tables, and 22 years for concrete tables. Two respondents who used combination wood and metal tables with the top and seats overlaid with fiberglass estimated their service life to be 12 and 20 years respectively.

Decay and vandalism were the chief causes for repair and replacement of picnic tables (fig. 3). Breakage as a result of normal use ranked second and theft ranked third. Most decay occurred in the tops and seats, which were continuously exposed to the weather, and in the base of table legs in continuous contact with the soil. Decay also occurred where table components were fastened together. It was not determined how many of the tables were treated with a wood preservative; however, the numerous reports of decay indicate that the use of preservative-treated wood was not prevalent. A survey of picnic facilities by the American Institute of Park Executives in 1960 found that an average of 41 percent of the picnic tables reported were treated with wood preservatives.[5] Decay could virtually be eliminated if agencies would pay $1 to $2 more per table for preservative-treated wood.

Vandalism ranged from carving on table tops to using the table for firewood. Theft was not a major problem. It has been reduced by the use of heavier tables and by anchoring tables in place.

Prices

The price of a picnic table will vary depending on several factors such as the source of supply, purchasing method used, number of tables purchased, construction material, and size and design of table.

FIGURE 3. — Decay in picnic tables seat. (F-518743)

All prices quoted by commercial manufacturers were f.o.b. factory for tables shipped unassembled. Many manufacturers give quantity discounts ranging from 10 percent to 30 percent depending on the quantity purchased. The prices of 6- to 8-foot wood tables ranged from about $20 to $43 f.o.b. factory. Prices of 6- to 8-foot wood-and-metal tables ranged from about $26 to $100. The price for an 8-foot wood-and-metal table with the top and seats overlaid with fiberglass was $80. An 8-foot table with top and seats consisting completely of fiberglass was priced at $110.

Shelters

Shelters are desirable structures in picnic areas. They provide picnickers with shade, protection from rain, and add to the general usefulness and enjoyment of picnic areas.

A total of 1,578 shelters was reported. About 80 percent of these were group shelters and the remainder were single-table shelters.

County, metropolitan, and municipal agencies accounted for the largest number of picnic shelters. Among the Federal agencies, the Corps of Engineers accounted for most of the

[5] *Bowen, Gordon S. Picnic facilities survey. Amer. Inst. Park Executives Bull. 5, p. 10. Wheeling, West Virginia: American Institute of Park Executives. 1961.*

shelters, followed by the Forest Service, Fish and Wildlife Service, and the National Park Service. On State-owned land, most of the shelters were found in State parks and State highway areas followed by State forest areas and State fish and game areas.

Picnic shelters may be grouped into five general types, based on major construction materials: wood, metal, masonry or stone, wood and metal, wood and masonry or stone, and "other."

About half the 1,578 shelters reported were constructed primarily of wood (fig. 4). Shelters made from wood in combination with concrete, stone, or brick ranked second with 23 percent of the total. Concrete, stone, or brick construction accounted for 20 percent of the total while metal, wood and metal, and "other" types made up less than 10 percent.

FIGURE 4. — A group picnic shelter made of wood. (F-518742)

The size of picnic shelters varied considerably. Single-table shelters averaged about 100 square feet of floor area each. However, group shelters ranged from around 300 square feet of floor area to 2,000 square feet of floor area. The amount of lumber required to build a shelter depends on the type and size of the shelter. A 20- by 30-foot rigid-frame design wood shelter requires from 1,800 to 2,000 board feet of lumber. Prices quoted for both wood and metal shelters ranged from about $2.00 to $2.20 per square foot f.o.b. factory.

Sanitary Facilities

Sanitary facilities on recreation areas consist of comfort stations, showers, laundry rooms, and dressing rooms. The most important type, to be discussed here, are comfort stations. They are essential for the continued use of any recreation area.

A total of 4,115 comfort stations were reported on recreation areas in the six States. About 55 percent of these comfort stations had 100 or more square feet of floor space each. The remainder contained less than 100 square feet each. Most of the larger comfort stations were on State park, county and metropolitan, municipal, and Corps of Engineer areas while most of the small comfort stations were found on Forest Service and county and metropolitan areas. Metropolitan and municipal areas had the largest number of comfort stations.

A variety of construction materials was used in comfort stations; however, wood predominated. About 45 percent of the facilities reported had wood as the major construction material. Twenty-four percent were of masonry or stone construction and 23 percent were a combination of wood and masonry, stone, or brick. Because they must be completely enclosed, these structures require a larger volume of lumber per square foot of floor area than do shelters.

Other Structures

Other structures often found on or near picnic areas are concession structures and benches.

Most of the concession structures were found on municipal recreation areas and on State parks. In some instances, these structures also served as museums and information centers. The major construction materials for these structures were wood, masonry, and stone, or some combination of these.

Benches ranked second to picnic tables in total number with over 38,000 reported. About 91 percent of these were found on municipal recreation areas and most were on recreation areas in cities with a population over 100,000. About 20 percent of the benches were constructed of wood only while 71 percent were a combination of wood and metal or concrete.

SUPPLIERS AND PURCHASING METHODS

Public recreation agencies may purchase their picnic ground equipment, make their own, or both. About 57 percent of the picnic tables reported were made by the agencies themselves. Fifteen percent were purchased from commercial manufacturers and another 15 percent from private contractors. The remainder were purchased from prison industries and other sources.

Agencies that make their own equipment obtain materials through local retail lumberyards. In some cases, these agencies purchase metal table frames from commercial manufacturers and construct the wooden tops and seats themselves. More than half the tables reported by the U.S.D.A. Forest Service, State park, municipal, and county and metropolitan agencies were made by agency personnel. County and metropolitan agencies made about 90 percent of their own tables.

It is not known how many commercial picnic table manufacturers there are in the United States. However, Thomas' Register of American Manufacturers lists 32 major manufacturers of picnic ground equipment. Most of these are located in the heavily populated, upper midwestern and northeastern United States. In addition to these firms, several furniture and playground equipment manufacturers make picnic ground equipment. Municipal and State agencies were the major users of commercially manufactured picnic tables.

State agencies utilized prison industries as a source of supply more than other agencies. State agencies also relied heavily on private contractors as a source.

Recreation agencies that purchase finished picnic ground equipment usually do so by means of competitive bids from commercial manufacturing firms or from private contractors. The type and design of equipment desired determine which manufacturer, or dealer, or contractor, will be invited to bid. Agencies rely on catalogs and advertising brochures in selecting prospective suppliers.

Some agencies that make their own equipment also purchase material on the basis of competitive bids, especially when the total value of the purchase is high.

DISCUSSION

Study results have some important marketing implications. First, they describe an important market that existing and potential wood industries may have overlooked in the past. The sale of materials and equipment to the recreation industry could be a profitable supplement to a firm's product line. Furthermore, this market may serve as a basis for the establishment of new woodworking firms in some areas. Assuming that the average life of a completely wood table is 10 years, and that the demand for recreation increases at its expected rate, 20 to 25 thousand new tables are required in the six-State area each year. About 2.0 to 2.5 million board feet of wood is required to build these tables. An additional 0.5 to 1.0 million board feet is required annually for shelters, comfort stations, and benches.

Second, a description of the types of structures being used and a recognition of how purchases are made, who the purchasers are, and where they are located will enable potential and existing manufacturers and suppliers to better delineate markets.

Finally, increasing competition from wood substitutes suggests that firms should make greater efforts toward applying existing techniques and knowledge in the use of wood. Firms should also experiment with new designs and finishes applicable to picnic structures and equipment.

• • •

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Hardwood Siding Performance, by Glenn A. Cooper. U.S.D.A. Forest Serv. Res. Pap NC-16, 11 p., illus., 1967.

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Oak Forests of the Lake States and their Management

JOHN L. AREND
HAROLD F. SCHOLZ

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Oak Forests of the Lake States and Their Management

John L. Arend and Harold F. Scholz

Oak forests occupy 6 million acres in Wisconn, Michigan, and Minnesota, or about 10 percent the commercial forest land (table 1). These forsts, which contain a total of 10 billion board feet sawtimber, produce about 195 thousand cords roundwood and 190 million board feet of sawmber annually (table 2). In addition to producing mber, the oaks are ideal multiple-use trees, proding excellent wildlife habitat and outdoor recreion opportunities.

able 1. — Distribution of oak stands in the Lake States by area and timber volume

State	Area	Volume	
		Total growing stock	Sawtimber
	M acres	M cu. ft.	M bd. ft.
Michigan[1/]			
Eastern UP	20	19,820	45,650
Western UP	73	87,280	189,240
Northern LP	1,296	864,640	1,954,800
Southern LP	1,016	585,010	1,933,450
Total	2,405	1,556,750	4,123,140
Wisconsin[2/]			
Northeastern	127	126,000	239,000
Northwestern	265	144,000	191,000
Central	888	459,000	1,106,000
Southeastern	216	178,000	619,000
Southwestern	1,075	780,000	2,429,000
Total	2,573	1,687,000	4,584,000
Minnesota[3/]			
Northeastern	26	19,821	30,910
Central	354	255,873	455,260
Southeastern	581	247,697	839,430
Western	79	55,063	160,510
Total	1,040	578,454	1,486,110
Total	6,018	3,822,204	10,193,250

[1/]Unpublished 1966 data, Michigan Forest Survey.
[2/]Wisconsin's forest resources (Stone and Thorne 961).
[3/]A third look at Minnesota's timber (Stone 1966).

About three-fourths of the oak forest in the Lake States is located in the southern portion of the region, which also has the best oak sites. Most of these stands are scattered farm woodlands; in Wisconsin, for instance, 72 percent of the oak acreage is owned by farmers.

Poletimber stands occupy nearly half the total oak area, and seedling and sapling stands about one-fifth (table 3). Many of these are well stocked, even-aged stands that originated from clear cuts in which all sawtimber on a woodland tract was harvested and the remaining small trees were either few in number or cut for firewood. Sawtimber stands, which occupy about one-third of the oak area, are mostly 90 or more years old and are most abundant in the southern portion of the region. Some of these stands on good sites are of high quality, but many others are understocked and decadent due to repeated high-grading.

In the northern portion of the Lake States, oaks now occupy much former pine land. Clear cutting of the pine followed by recurrent fires enabled the persistent oaks, which resprout quickly after fires, to become established.

Table 2. — Annual timber cut from oak stands in the Lake States

State	Sawtimber	Poletimber	All timber
	Million bd. ft.	M cords	M cu. ft.
Michigan[1/]	69.1	35	14,349
Wisconsin[2/]	92.8	115	31,102
Minnesota[3/]	29.0	45	8,773
Total	190.9	195	54,224

[1/]Unpublished 1966 data, Michigan Forest Survey.
[2/]Wisconsin's forest resources (Stone and Thorne 1961).
[3/]A third look at Minnesota's timber (Stone 1966).

Table 3. — Distribution of oak area in the Lake States by stand-size class
(In thousand acres)

State	Stand-size class				
	All stands	Sawtimber	Poletimber	Seedling and sapling	Nonstocked
Michigan[1/]	2,405.0	725.7	1,035.1	512.4	131.8
Wisconsin[2/]	2,573.0	855.0	933.0	785.0	--
Minnesota[3/]	1,039.5	366.8	527.7	145.0	--

1/Unpublished 1966 data, Michigan Forest Survey.
2/Wisconsin's forest resources (Stone and Thorne 1961).
3/A third look at Minnesota's timber (Stone 1966).

PRINCIPAL OAK SPECIES OF THE LAKE STATES[1]

At least 10 species of oak are found in the Lake States: (1) northern red oak,[2] (2) black oak, (3) pin oak, (4) scarlet oak, (5) northern pin oak, (6) shingle oak, (7) white oak, (8) swamp white oak, (9) chinkapin oak, and (10) bur oak. However, only five species — northern red, black, northern pin, white, and bur oak — are commonly found over most of the region. Moreover, only northern red, white, and black oak ordinarily produce commercially valuable timber (table 4).

The Lake States are the northern limit of the range of most oaks discussed here, so the oaks are most abundant in the southern portion. The forest environment varies greatly, being most favorable for oaks in the southeast and becoming less favorable in the north and west. Because of differences in climate, growing season, and soils, the forest vegetation gradually changes from oaks and mixed hardwoods in the south to hemlock-northern hardwood forest in the north, and to prairie in western Minnesota. These environmental differences affect species distribution, physical and morphological characteristics, growth rates, and value of the oaks for timber products.

Table 4. — Oak volume in the Lake States by species group

State	Sawtimber	Total growing stock
	Million bd. ft.	Million cu. ft.
RED AND BLACK OAKS		
Michigan[1/]	3,094.2	1,156.3
Wisconsin[2/]	3,378.0	1,222.0
Minnesota[3/]	885.4	373.6
Total	7,357.6	3,751.9
WHITE OAKS		
Michigan[1/]	1,029.0	400.5
Wisconsin[2/]	1,206.0	465.0
Minnesota[3/]	600.7	4/204.9
Total	2,835.7	1,070.4

1/Unpublished 1966 data, Michigan Forest Survey
2/Wisconsin's forest resources (Stone and Thorne 1961).
3/A third look at Minnesota's timber (Stone 1966).
4/Mainly bur oak.

NATURAL ENEMIES

Although the oaks have many natural enemies only oak wilt and the heart-rotting fungi cause major damage. Trees of the white oak group appear to be slightly more resistant to insect and disease attacks than those of the red oak group.

[1] *For detailed silvical characteristics see: Silvics of forest trees of the United States. U.S. Dep. Agr., Agr. Handb. 271, 762 p., illus. 1965.*

[2] *Common and scientific names of trees listed on inside back cover.*

Late spring frosts frequently kill the lower foliage and developing acorns of all oaks; the most serious damage from frosts is periodic loss of acorn crops.

Oaks are the preferred host of many insects, but few kill or even seriously damage the living trees. Foliage-eating insects, such as the fruit-tree leaf roller (*Archips argyrospilus* (Walker)) and walkingstick (*Diapheromera femorata* (Say)) may completely defoliate an oak without killing it (Craighead 1950). A leaf roller (*Archips semiferanus*) similar to the fruit-tree leaf roller is currently causing extensive damage and some tree mortality to oaks in northeastern Lower Michigan. Gall insect attacks on the roots, bark, twigs, buds, leaves, flowers, and acorns result in numerous deformities and distorted growth, but cause little real damage (Felt 1965). Larvae of various oak borers may cause cull or grade losses, especially in the butt logs.

The acorns are seriously damaged by weevils of the genus *Curculio*. At least 60 percent and more often 90 percent of the fallen acorns are infested by insects, which greatly increases the difficulty of obtaining natural oak reproduction. No practical control has been devised to protect acorns from insects.

Most diseases of oaks are caused by fungi and result only in defects and cull. However, oaks may be killed by the oak wilt fungus (*Ceratocystis fagacearum* (Bretz) Hunt), which blocks the conductive tissues of the trees. All the oaks are susceptible to oak wilt, but the red and black oaks have less resistance than the white oaks to this disease. No practical control method has been developed for forest trees.

Butt rot often develops in pole-size and larger oaks that have been damaged by burning or logging. Decay is also common in tops of older trees, where the infection may start in large branch stubs as the tree approaches maturity.

A common heart-rot fungus that causes extensive cull in red and black oak sawtimber is *Fomes everhartii*. Another fungus causing serious damage to oak is *Armillaria mellea* Fr., which attacks the roots of oak that have been weakened by drought or soil compaction in parks and camping areas.

Phomopsis tumor of oaks forms large stem galls that often reach several feet in diameter. *Strumella* canker is found on young oaks with smooth bark. This fungus causes sunken lesions an inch to a foot or more in length (Baxter 1952).

OAK SITE-PRODUCTIVITY CLASSES

The species composition of oak stands, their growth, timber quality, and economic importance are influenced most by factors that affect soil moisture: soil depth and texture, aspect, position on the slope, and climate. The combined effect of these environmental factors on tree growth is the basis for site-productivity classification.

Available soil moisture affects stand composition on otherwise similar sites. For example, black oak usually is the predominant species on ridges in southern Michigan, but farther west where precipitation is less abundant, such sites most often support bur oak. In contrast, northern red oak often is the prevailing species on sites with optimum soil moisture.

The physical characteristics of the trees are also related to site quality; the bark of most oaks is rougher and the trees are shorter, limbier, and less valuable for timber on dry sites than on moist ones. Although oaks may be found growing over a range of sites, they produce quality timber only on good sites. Thus, proper management of oak stands requires an understanding of site potential in terms of volume and value growth for different species.

The need to correlate site productivity with the growth, yield, and occurrence of oak species for management purposes has long been recognized in the Lake States. Deters (1943) noted that the soil-moisture gradient association among the oaks in southeastern Minnesota was related to the topographic position. Bur oak occupied the driest sites and northern red oak the wettest.

More recently, Gysel and Arend (1953) reported that oak sites in southern Michigan could be classified on the basis of (1) subsoil texture, (2) slope steepness, (3) slope position, and (4) depth of the moist layers in the substrate. In southern Michigan the soils are deep and the terrain only slightly to moderately rolling, having maximum differences in elevation of only 100 to 200 feet. Consequently, soil depth and aspect (exposure) have less effect on site quality here than in the unglaciated hills of southern and southwestern Wisconsin and southeastern Minnesota.

The landforms in southwestern Wisconsin and southeastern Minnesota differ from those in southern Michigan. Soil depth varies from a thin mantle of loess or residual material underlain by limestone or sandstone bedrock to deep talus deposits on lower slopes and in valleys. The topography ranges from flat uplands to steep, sometimes precipitous slopes with local differences in elevation of as much as 500 feet. Under these conditions, soil depth, aspect, and character of the parent rock also greatly affect site productivity.

Practically all investigations of soil-site relations in other geographic areas show that the soil and topographic features that affect the quantity of available soil moisture largely determine site productivity for oak. Studies include those by Einspahr and McComb (1951) in adjacent northeastern Iowa; Gaiser (1951) and Carmean (1967) in southeastern Ohio; Trimble and Weitzman (1956), Doolittle (1957), and Trimble (1964) in the Appalachians; Smalley (1967) in northern Alabama;

and Arend and Julander (1948) in the Ozarks. Soil fertility alone has been shown to have only a slight effect on height growth of oaks in the limited studies conducted to date (Lunt 1939).

In summary, then, the investigations cited show that the soil and land features affecting available soil moisture largely determine site productivity for oak species in a given geographic area. Although the soil and land features of the Lake States vary greatly in both geologic origin and character of terrain, five factors, (1) soil texture, (2) soil depth, (3) position on slope, (4) steepness of slope, and (5) aspect or exposure, generally reflect oak site productivity (table 5).

Coarse-textured, rapid-draining sands generally are poor oak sites, whereas the finer textured loams and silt loams, with their greater water-retention capacity, favor faster growth. Lower slopes are usually more productive than upper slopes and ridges, even when soil depth and texture are similar. Oaks grow faster on north and east than on south and west exposures.

The most commonly used index of site productivity is the total height-age relation (site index). This relation is reasonably accurate for free-growing oaks 35 to 80 years old. It is not reliable for oaks that are much younger or older, or for trees that have been periodically suppressed.

OAK FOREST TYPES BY SITE-PRODUCTIVITY CLASS

The oak species or combination of species found on a site not altered by cutting or other disturbances is usually an indication of the site productivity. For example, red oak is generally found on the most productive sites, mixed oaks on medium to good sites, and black oak, bur oak, and northern pin oak on the poor to very poor sites. Only the most common and most extensive natural species associations, in which oaks should be given specific consideration in timber management, are described here.

On the most productive oak sites more shade-enduring species usually become dominant in natural succession. However, the oaks are reasonably stable ecologically on medium- and poor-quality sites (Parmelee 1953a, 1953b).

Table 5. — Soil and topographic features affecting site productivity of oak forests in the Lake States

Site quality	Site index and growth potential at age 80 1/				Soil features and corresponding topographic features 2/	
	Site index	Number 16-foot logs	Mean annual growth per tree	Periodic annual growth per acre	Soil	Topography
			Cu. ft.	Bd. ft.		
Good	70+	2½+	0.4-0.6	200-300	A. Deep, moderately and well-drained silts, loams, and clays where soil depth is 3 feet or more to parent rock; sands where water table is within 4 to 10 feet of the surface.	A. On relatively flat topography, broad ridges, lower slopes, bottoms, and valley coves; all north and east slopes where gradients are less than 20 percent; middle north and east slopes where gradients range from 20 to 35 percent.
Medium	55-65	1½-2½	.3- .4	100-200	A. Moderately deep (20 to 36 inches) silts, loams, and clays, or deep sands, with fine-textured bands in subsoil 2 to 6 inches in thickness at depths less than 60 inches. B. Deep sands. C. Deep silts and loams.	A. On relatively flat land, upper and middle north and east slopes where gradients are less than 20 percent; middle north and east slopes where gradient range from 20 to 35 percent. B. On lower slopes in rolling topography. C. On upper and middle south and west slopes where gradients ar less than 20 percent.
Poor	40-55	½-1½	.1- .2	Less than 100	A. All shallow soils less than 20 inches in depth and deep porous sands. B. All soils. C. All soils.	A. On flat topography. B. On narrow ridges and upper slopes in hilly topography. C. On middle south and west slopes where gradients exceed 20 percent.

1/ Measurements from dominant trees (red oak group) in unmanaged stands.
2/ Does not apply to prairie soils and loessial deposits.

In describing the species associations of the Lake States in which oaks are important, it was not always practicable to use standard forest-type designations (Society of American Foresters 1954). When possible, however, the SAF type number or numbers most nearly applicable are shown. Because there is no satisfactory basis for estimating the total acreage of each of the major forest types, their area is given only in general terms.

Good Sites

Northern Red Oak in Mixture With Other High-Value Hardwoods

(Includes SAF Type 54)

Northern red oak is the key overstory species in this, the most productive oak type in the Lake States. The type is usually limited to good-to-excellent sites in Lower Michigan, the southern two-thirds of Wisconsin, and the southeastern quarter of Minnesota.

The associated species in these "mixed hardwoods" forests vary somewhat across the region. In Michigan this type includes a wide mixture of hardwoods, such as northern red oak, white oak, American basswood, black cherry, white ash, rock, slippery, and American elms, black walnut, red maple, sugar maple, beech, and frequently yellow-poplar (fig. 1). In Wisconsin, northern red oak usually is found with white ash, sugar maple, red maple, slippery elm, and occasionally bigtooth aspen and butternut.

F-519092

FIGURE 1. — Northern red oak growing in mixture with other valuable hardwoods. A 26-inch d.b.h. yellow-poplar is being measured. Baker Woods near East Lansing, Michigan.

Northern Red Oak

(SAF Type 55)

This oak type is limited in the Lake States. In southwestern Wisconsin and in extreme southeastern Minnesota northern red oak forms fairly extensive stands. Equally "pure" but more limited acreages also occur on moist sites in northwestern Lower Michigan, southeastern and north-central Wisconsin, and east-central Minnesota. This forest type requires more mesic conditions for its best growth than the northern red, white, black oak and hickory mixture described for medium sites.

Northern red oak stands are typically even-aged and well stocked with high-quality timber (fig. 2) (Scholz 1946, 1952). This type is often composed of less than 10 tree species, with the bulk of the stocking in red oak (Scholz 1960).

The existing red oak stands are not very stable ecologically, because tolerant hardwoods usually become established and gradually shade out the oak in succeeding rotations. However, some ecologists feel that northern red oak forests can persist as a subclimax type for extended periods (Marks 1942). There are cases, too, where stands of sugar maple and American basswood were destroyed by fire or other catastrophes and subsequently were replaced by more xeric stands "rich" in northern red oak (Curtis 1959).

F-519089

FIGURE 2. — The growth potential of northern red oak stands is excellent. This stand near Whitehall, Wisconsin (Trempealeau County) is about 100 years old and averages 110 square feet of basal area per acre. Overstory trees are almost exclusively northern red oak up to 22 inches in diameter and 65 to 76 feet in total height.

White Oak

(SAF Type 53)

White oak grows in pure or nearly pure patches an acre or two in size on good sites in southwestern Wisconsin and southeastern Minnesota (fig. 3), but usually is found in mixture with other oaks. It is second to northern red oak in regional importance for timber, and the most valuable oak in the Lake States for high-quality sawtimber. It is considered the only satisfactory timber for the tight cooperage industry. Its heartwood is more durable than the other oaks, has a more attractive appearance, and usually is finer textured; therefore, it is in high demand for posts, piling, barrel staves, lumber, and veneer.

White oak tolerates site conditions ranging from dry sands to deep, fertile, moist-but-well-drained loams. On dry sites, it is a low-quality, small-diameter tree associated with such species as northern pin oak, black oak, and quaking aspen, but on good sites white oak produces excellent timber.

F-519091

FIGURE 3. — White oak is also an excellent quality timber tree. These white oaks are growing in southwestern (La Crosse County) Wisconsin.

Northern Red Oak in Mixture With Northern Hardwoods

(Includes Species Found in SAF Types 25, 26, 27, 60)

This highly productive type represents a near-final successional phase in the change from northern red oak to northern hardwood forest. Northern red oak is still important, but, nevertheless, secondary to sugar maple and other northern hardwoods in these stands (fig. 4).

F-519093

FIGURE 4. — Northern red oak is found as scattered, fast-growing, high-quality trees (the one shown here is 17 inches at d.b.h. and about 60 years old) in the northern hardwood-conifer complex of northeastern Wisconsin. Associated species on this site included sugar maple, red maple, yellow birch, eastern hemlock, black ash, American elm, American basswood, white pine, and balsam fir. Chilsen Timber Harvest Forest, Lincoln County, Wisconsin.

In the northern hardwood forests of Upper Michigan and the northeastern two-thirds of Wisconsin, northern red oak is present only as single, scattered trees of high quality. This has led many foresters to feel that a greater effort should be made to propagate northern red oak in northern hardwood stands, where it usually grows faster than sugar maple. However, the natural succession in such stands is toward the more shade-enduring species, especially sugar maple. Northern red oak is less tolerant and will be difficult to maintain on these sites even in its present role.

Medium to Good Sites

Northern Red Oak-White Oak-Black Oak-Hickory Type

(Includes SAF Types 52-53)

This combination of key species probably accounts for the largest acreage of oak forest in the Lake States. In general, the type occupies the drier sites of medium to good productivity (fig. 5).

F-519099

FIGURE 5. — This mixed oak type is the most prevalent oak type in the southern portion of the Lake States.

Composition varies widely, with complex tree associations in the eastern part of the region and relatively simple ones in the west. Species (such as flowering dogwood, sassafras, and pignut and bitternut hickory) common in Michigan are rare or absent in Wisconsin and Minnesota. Bur oak is much more likely to be found in this type in Minnesota and Wisconsin than in Michigan. In southern Wisconsin large bur oaks are often found scattered among younger northern red and black oaks. In these stands the younger oaks developed after wildfires were largely curtailed by agricultural development (Marks 1942, Parmelee 1953a, Curtis 1959).

Black oak plays an interesting role in this forest complex. In Lower Michigan and southeastern Wisconsin it is one of the important species in the stand, but in southwestern Wisconsin and southeastern Minnesota it becomes secondary in importance to northern red oak and white oak. Because high-quality white oak was in such great demand during the past century, many mixed oak forests where half the original sawtimber volume was white oak now are predominantly northern red oak and black oak.

Mixed Oak-White Pine Type

(SAF Type 20)

A combination of white pine, northern red oak, white oak, and associated hardwoods occupies a limited acreage in the central third of Wisconsin and parts of south-central Michigan (fig. 6). Occasionally both red and white pines are found in these mixtures, but more commonly scattered "old-growth" white pines are found encompassed by vigorous second-growth hardwoods, especially northern red oaks. Although the hardwoods account for most of the basal area in such stands, the individual white pines often constitute a major portion of the sawtimber volume.

This forest type is of interest mainly because of the high value of the large pines. It has temporary ecological status. Few white pine saplings and poles are present because they are unable to compete successfully with the more tolerant and vigorous decidious trees. Consequently, pines will virtually disappear from the forest association once the scattered large trees die or are cut.

F-519094

FIGURE 6. — Scattered old-growth eastern white pines in mixture with second-growth northern red oaks and other hardwoods on the Apple River Timber Harvest Forest in Polk County, Wisconsin. Note the clump of eastern white pine on the skyline in the central portion of the picture. The total basal area of the stand at this particular location was 90 to 100 square feet per acre.

Poor Sites

Black Oak-Hickory Type

(Resembles SAF Types 40 and 52)

Mixed oak stands that are predominantly black oak with scattered white oak grow on many droughty sites, such as upper slopes and narrow ridges, in southern Michigan and southeastern Wisconsin. Unlike its moist-site counterpart, this type includes very few northern red oak, white ash, sugar maple, or other mesic species. An interesting thing about this type is that the percentage of black oak in the stand increases as site quality decreases, and sometimes even form a pure subtype in patches of a few acres. The type includes most of the poorer oak lands in the southern portion of the region (fig. 7).

F-518098

FIGURE 7. — A very poor oak site near the top of a steep slope on deep sand in Ionia County, Michigan. The trees are all black oaks, averaging 8 inches in diameter, 43 feet in height, and 68 years in age. Note the limby, crooked boles.

Northern Mixed Oak Complex

(Similar to SAF Type 14)

This oak type predominates on many droughty, outwash plains that formerly supported mixed stands of pines and hardwoods, and on other dry, sandy sites in the central portion of northern Lower Michigan, central and northern Wisconsin, and east-central Minnesota (fig. 8).

F-519090

FIGURE 8. — This stand of 4- to 12-inch trees is typical of the northern pin oak complex. It occupies a droughty site of Grayling sand soil in an area where the original forests were a mixture of pines and hardwoods. The stumps are white pine.

The recurrent fires that followed cutting of the virgin pine stands built up the stocking of the oaks, because oaks, unlike pines, sprout vigorously from stumps. Thus, these second-growth forests of sprout-origin oaks have taken over a total area of about 2 million acres.

Although this forest type often has been referred to as "scrub oak," well stocked stands will average 10 cords of pulpwood per acre at 60 to 70 years (Arend 1964). However, the trees are often limby and defective from basal fire wounds.

The oaks present in this type include black oak, northern red oak, white oak, and northern pin oak. The oaks in the red and black oak group are difficult to distinguish because of overlapping physical characteristics of the leaves, acorns, buds, and bark. Other forest species may include red maple, aspen, cherry, and scattered jack pine, white pine, and red pine (table 6).

Bur Oak Type

(SAF Type 42)

Bur oak has the most extensive botanical range of the oaks in this region. As a pure type, however, it is confined mainly to the prairie-fringe soils and dry, shallow soils in the southern two-thirds of Wisconsin and Minnesota. In Wisconsin, such stands usually occupy the poorest sites and rarely are more than an acre or two in size, but in Minnesota, bur oak stands are more numerous and extensive.

Table 6. — Species composition and stand structure of northern mixed oaks on Grayling sand in northern Lower Michigan at 60 to 70 years of age[1]

(In number of trees per acre)

Species	D.b.h. class (inches)			
	1 to 4	5 to 9	10 to 16	All classes
White oak	197	50	6	253
Red and black oaks	86	40	12	138
Red maple	161	0	0	161
Aspen[2/]	30	11	0	41
Cherry[3/]	8	1	0	9
Jack pine	14	2	0	16
Serviceberry	23	0	0	23
Miscellaneous	81	0	0	81
Total	600	104	18	722

1/Based on 7 1/2-acre plots located in Wexford, Lake, Manistee, and Grand Traverse Counties, Michigan.

2/Includes both *Populus tremuloides* and *P. grandidentata*.

3/Includes *Prunus serotina* and *P. virginiana*.

In 1966 bur oak accounted for roughly one-fourth of the cubic-foot volume of all oak growing stock in Minnesota (table 4).

Bur oak, like white oak, can adapt to a variety of physical sites, both dry and moist. A pioneer species, it persisted on subclimax prairies of the Midwest in spite of wildfires (Deitschman 1958). Bur oak is usually short-boled, limby, and slow-growing in this region, but occasionally high-quality trees are sold along with white oak.

The main value of the bur oak type is to protect the land from erosion and to provide food and shelter for wildlife. Bur oak stands may have a potential value for picnic and campground sites (fig. 9).

F-519097

FIGURE 9. — Bur oak can provide excellent shade for picnic grounds and camping sites.

NATURAL REGENERATION OF OAKS

Most oak reproduction originates from stump sprouts and seedling sprouts. Oak seedlings grow slowly and, unless they receive adequate sunlight, the tops die back and new sprouts arise from the root system. Oak sprouts, because of their larger root system, grow much faster and can survive and grow in more subdued light than seedlings. Of course, nearly full sunlight is optimum for the best growth of either.

Seed Production

The acorns produced by species in the red and black oak group mature in about 18 months, drop to the ground in the fall of the second growing season, and germinate the following spring. Thus, these acorns are exposed to weather, insects, and animal damage longer than white oak acorns, which mature in one growing season. Both oak groups flower when the leaves come out in May, but white oak acorns mature by late September or early October, drop to the ground, and germinate during the fall.

The frequency and size of acorn crops vary somewhat by species, crown size, exposure to light and weather. Acorn production differs greatly between individual trees — some bear acorns nearly every year while others seldom yield any; thus, acorn yields are nearly impossible to predict. However, some seed is produced each year in most oak stands.

Korstian (1927) found an average of about 4,900 acorns per tree from 12 white oak and 9 black oak trees during a single season, but the remaining 16 oaks in his 37-tree sample produced no acorns. In the Missouri Ozarks, Burns, Christisen, and Nichols (1954) found that black oak produced 4,700 to 7,400 acorns, and white oak 3,400 to 4,600 per tree during the best 3 years out of 6. Gysel (1957) also found that white oaks generally produced fewer acorns than black and red oaks in Michigan. A summary of tree characteristics and environmental influences found to affect acorn production includes the following:

1. Most oaks begin to produce viable acorns at age 20 to 30 years, but optimum yields are not generally reached until age 50 to 75.

2. Acorn production generally increases with d.b.h. up to about 20 inches, but crown size is probably most important (Downs and McQuilkin 1944).

3. Dominant trees generally outproduce codominants. The south and west sides of the crown yield more acorns per unit area than the north and east sides (Gysel 1956).

4. Late spring frosts may damage the developing acorns. Warm (above normal) temperatures during the last 10 days of April followed by cool

(subnormal) temperatures the first half of May result in the best white oak acorn yields, but steadily warming spring temperatures result in poor yields (Sharp and Sprague 1967).

5. Site quality appears to affect only the weight of the acorn crops (Gysel 1957).

Insects, diseases, and animals further deplete the annual acorn crop. Korstian (1927) found that over half the total acorn crop was lost to animals, and that when all losses were totaled, less than 7 percent of the original crop was available to produce seedlings. Other studies have shown that insects and animals destroy roughly four-fifths of the annual acorn crop (Minckler 1957, Downs and McQuilkin 1944, Gysel 1957). Duvendeck (1962) found that deer will eat about 1.5 pounds of acorns per day per hundredweight in the winter.

Unfortunately, few measures can be taken to increase the number of viable acorns produced under natural forest conditions. At the present time, foliage sprays or chemicals injected into the stem to control acorn-attacking insects, and such positive control as poisoning rodents, are either impractical or unacceptable to the general public. Banding, choking, or partially girdling trees in southern Michigan did not increase acorn production. Fertilizing may increase acorn production.

The most positive cultural measure that can be used to increase acorn production is to favor trees that are good acorn producers in thinnings or improvement cuttings, thus providing more room and light for trees that regularly yield heavy seed crops.

Seedling Establishment

The failure of viable acorns that escape spoilage or destruction to become 1-year seedlings usually can be traced to one of two causes: either the seed dries out, killing the embryo, or the newly formed radicle fails to penetrate into mineral soil.

Viability decreases markedly when acorn moisture content falls below 50 percent of ovendry weight for white oak, or below 30 percent for northern red oak (Korstian 1927).

The ideal seedbed for oak acorns is moist, well-drained mineral soil protected by some litter. However, Minckler and Jensen (1959) found litter depths in excess of 1 inch to be detrimental to the establishment of oak seedlings in southern Illinois. Our observations indicate that oak seedlings are more numerous where the mineral soil has been disturbed, such as logged areas, fire lanes, and the edges of cultivated fields. Both northern red and white oak seedlings are also able to develop on sparse, grassy sites. Oak seedlings rarely are found in places where litter accumulates, such as depressions, around old logs, and in thickets of shrubs. Apparently several inches of litter prevent the radicles of germinating acorns from reaching the underlying mineral soil.

The most practical treatment to increase seedling establishment is partial cutting, because it disturbs the forest floor and lets in more light. Other practices might include prescribed burning to consume deep litter, and soil scarification to expose mineral soil a few years before the final harvest cut. Scarification would also work many of the viable acorns into the mineral soil where they are less likely to be eaten by animals and damaged by excessive drying. Of course, once oak seedlings are established, nearly full sunlight is required for their survival and growth.

Sprouts

Most of the present-day second-growth oak stands are of seedling sprout and stump sprout origin. All of the oaks indigenous to the Lake States have dormant buds along the stem that produce sprouts when the tree is cut or damaged. Although the physiological mechanism is not fully understood, sprouting is apparently controlled by hormones. Vogt (1966) showed that auxins produced by apical buds are translocated to the dormant buds, where they act as growth inhibitors. Interruption of the auxin flow, which occurs when the crown is removed or damaged, initiates sprouting.

Sprouting ability generally decreases with age, although some oak species are prolific sprouters even after the trees reach sawtimber size, especially on good sites. Sudden exposure to light following heavy cutting also appears to stimulate sprouting.

Prior to investigations by Liming and Johnston (1944) in the Missouri Ozarks, foresters had recognized only two types of oak reproduction: seedlings and stump sprouts. The term "seedling" also included seedling sprouts because it was generally assumed that the tops of such young oak were within 2 or 3 years of the age of the roots. But the Missouri study showed that more than half of the so-called seedlings actually were sprouts whose root systems (called stools) were many times as old as the tops. The amount of defect associated directly with the stools was low and the annual height growth of white oak and black oak stool sprouts was more than double that of true seedlings of the same species. This study made two important contributions to our knowledge of oak management. First, it explained how a forest gradually builds up a reproduction potential by means of standby root systems that retain their capacity to produce new tops as needed for 20 years or more. And second, it showed that properly selected sprouts provide acceptable growing stock for the next rotation of timber. Similar observations were made in southeastern Ohio by Merz and Boyce (1956).

There has been a long-standing and perhaps still unresolved question as to whether stump sprouts are as desirable as seedlings and seedling sprouts. Apparently this depends upon the size of the tree from which the sprout develops and almost certainly upon the number of times that the same root system has had to serve for successive rotations of sprouts. For example, Scholz (1931) reports that "repeated coppicing for a period of over two hundred years has reduced the vitality of the growing stock" in the Hudson River highlands of New York. Increment borings taken in conjunction with this study showed that a high percentage of outwardly sound oak sawtimber trees had heart rot. No doubt repeated coppicing on short rotations may reduce the quality and vigor of oaks. However, first-rotation oak stump sprouts are as vigorous and tall as single-stem trees at 45 years of age (Trimble 1968).

Manipulating sprout production is important in oak management. To encourage sprouting, oaks should be cut during the dormant season, leaving the stumps as low as possible. Because full sunlight on the stump also stimulates sprouting and subsequent sprout growth, cutting groups of trees is beneficial. Where oak sprouts are not desired, trees should be cut or girdled at the peak of the growing season (Clark and Liming 1953). Of course, the most feasible method of controlling oak sprouts is with herbicides, either stem-injected or sprayed on the foliage of sprouts that have developed.

HARVEST CUTTING METHODS TO REGENERATE OAK STANDS

When oak stands reach maturity, the harvest method used should ensure establishment of a new stand of trees of desirable species. The cutting method recommended will depend on the presence or absence of adequate advance reproduction of desirable species. Adequate reproduction means at least 400 well established seedlings or seedling sprouts per acre that are 1 foot or more in height (U.S.D.A. Forest Service 1962). Where advance reproduction is adequate and the main stand is mature, complete overstory removal is recommended. Where advance reproduction is inadequate, the rotation must be prolonged by a series of partial cuttings or other stand disturbances. One advance reproduction is adequate, the remaining overstory is removed.

Advance Reproduction Is Essential

Obtaining enough advance oak reproduction to regenerate the stand is a major problem on certain sites in the Lake States. Although ample reproduction is present under most mature oak stands, the percentage made up by oak varies with the productivity of the site. For example, Arend and Gysel (1952) found from 5 to 17 thousand stems per acre in trees less than 0.6 inch d.b.h. under well stocked, ungrazed oak stands in southern Michigan. However, oak constituted only 5 percent on good sites, 15 percent on poor and medium sites, and 50 percent on very poor sites. Studies in West Virginia and western Maryland also showed less oak reproduction on good sites (Weitzman and Trimble 1957, Carvell and Tryon 1961).

Even when oak reproduction is present in sufficient quantity, it is frequently not tall enough to compete with ground vegetation and seedlings of undesirable species. For example, in southern Wisconsin, a sample of the reproduction beneath two oak sawtimber stands on medium to good sites showed 4 to 10 thousand stems per acre (table 7). Although oak reproduction made up one-third to one-half of the total, it was mostly under 1 foot in height, much smaller than the competing black cherry and red maple. When the overstory trees were removed in these stands, the new stand was composed mainly of species that had a height advantage in the reproduction stage.

The same amount of shade and competition for moisture that keeps oak reproduction suppressed year after year does not prevent the development of young red maple, black cherry, and other hardwoods under mixed stands of oak in Wisconsin (Larsen 1953). Similarly, in oak forests of southern Michigan, red maple, hickory, white ash, and black cherry saplings often dominate the reproduction in oak forests, even though they usually make up only a minor portion of the overstory (Parmelee 1953a). A study of environmental factors favoring advance reproduction under oak stands in West Virginia showed that stand disturbance during the previous 20 years was most important in establishing oak reproduction, and its subsequent development was directly related to the amount of sunlight reaching the forest floor (Carvell and Tryon 1961). The vigor and shape of the crown also affect the growth of advance oak reproduction. Carvell (1967) found that oak seedlings with flat crowns grew more slowly than those with normal crown shapes.

Advance reproduction has an important role in oak management for many reasons. First, it must be present in adequate amounts before the final harvest cut if the stand is to be successfully regenerated. Second, the thrifty tree species present in the advance reproduction before the final cut will dominate the new stand. Third, advance reproduction builds up in numbers following stand disturbance (Liming and Johnston 1944, Carvell and Tryon 1961, Ward 1966). Therefore, improvement cuttings and thinnings to eliminate undesirable trees and regulate stand density, especially during the 20 years before the final harvest cut, can help improve the quantity and composition of the advance reproduction.

Table 7. — Tree reproduction in two oak sawtimber stands with brushy understories in southern Wisconsin[1]

(In stems per acre)

Plot	Height class	Red oak	Black oak	White oak	Hickory	Black cherry	Misc. hwds.	All species
ALBANY WOODS (GREEN COUNTY)								
1-1	Under 1'	0	3,550	0	0	400	0	3,950
	1-5'	0	0	50	0	1,900	50	2,000
	5'+	0	0	50	0	0	0	50
	Total	0	3,550	100	0	2,300	50	6,000
2-1	Under 1'	0	1,650	100	150	2,800	300	5,000
	1-5'	0	50	150	100	6,250	200	6,750
	5'+	0	0	0	0	1,000	0	1,000
	Total	0	1,700	250	250	10,050	500	12,750
3-1	Under 1'	0	6,050	150	100	1,100	0	7,400
	1-5'	0	700	50	0	1,950	50	2,750
	5'+	0	0	0	0	800	0	800
	Total	0	6,750	200	100	3,850	50	10,950
4-1	Under 1'	1,550	1,900	850	0	2,550	0	6,850
	1-5'	800	0	350	0	700	300	2,150
	5'+	50	0	0	0	0	250	300
	Total	2,400	1,900	1,200	0	3,250	550	9,300
	Stand average	600	3,475	437	88	4,862	288	9,750
COULEE EXPERIMENTAL FOREST (LA CROSSE COUNTY)								
1-1	Under 1'	850	0	100	25	150	1,075	2,200
	1-5'	0	0	25	25	225	2,800	3,075
	5'+	0	0	25	0	0	400	425
	Total	850	0	150	50	375	4,275	5,700
2-1	Under 1'	275	0	125	50	50	400	900
	1-5'	25	0	0	50	0	450	525
	5'+	0	0	0	0	0	200	200
	Total	300	0	125	100	50	1,050	1,625
3-1	Under 1'	175	0	0	75	25	1,025	1,300
	1-5'	0	0	0	25	0	1,175	1,200
	5'+	0	0	50	0	0	25	75
	Total	175	0	50	100	25	2,225	2,575
4-1	Under 1'	1,600	0	1,475	400	175	350	4,000
	1-5'	525	0	425	0	25	450	1,425
	5'+	25	0	25	50	25	150	275
	Total	2,150	0	1,925	450	225	950	5,700
	Stand average	869	0	562	175	169	2,125	3,900

1/ 4 randomized blocks, each containing 4 1-acre-square plots, were established in each of these 2 oak stands. Results are based on 20 milacre quadrats in the Albany Woods and 40 milacre quadrats in the Coulee Forest randomly located in each of the 4 1-acre-untreated control plots.

Brush Makes Regeneration Difficult

Some sawtimber oak stands, primarily those in southern and western Wisconsin and Minnesota, have dense, brushy understories that cause an unusual regeneration problem. The major species recorded in two such stands in southern Wisconsin were blackberry, raspberry, gray dogwood, hazelnut, gooseberry, and numerous others totaling 13 to 17 thousand stems per acre (table 8). Although tree reproduction was ample in these stands, advance oak reproduction was sparse.

Why unusually dense, brushy understories are present in some sawtimber stands in southern Wisconsin and Minnesota and not in others is not clear. These understories are found most often on medium to good oak sites where the overstory sawtimber trees are mainly first-rotation oak and scattered old-growth bur oaks. These stands developed in the prairie fringe areas after agricultural settlement had largely controlled wildfires. According to Cottom (1949), early surveyors in this area recorded the vegetation as "scattering timber," with an understory of "hazel," "prairie grasses," "red root" (*Ceanothus*), and "oak." Cottom found many present-day oak stands in Wisconsin containing bur oak, black oak, and shagbark hickory to still have a shrub understory of hazel, dogwood, and blackberry. Much of this area was initially covered with a thin mantle of loessial top soil that may also favor development of a lush ground cover under a dense, mature oak overstory.

Clear-Cut Method

Most of the ungrazed, reasonably well stocked sawtimber stands of oak in the Lake States will have ample advance reproduction when the stands are mature. The proportion of oak in these stands will depend upon such things as site, stand density, and previous disturbances. When the advance reproduction is satisfactory, removing all overstory trees at once will generally result in successful stand regeneration (fig. 10). Additional reproduction can be expected from stump sprouts after harvest cutting, but new seedlings usually fail to compete with the advance reproduction and sprouts. Even where dense, brushy understories exist, the advance tree reproduction, if knocked down in logging to promote sprouting, will normally outgrow the brush in 5 to 10 years.

Table 8. — Brush species found in two sawtimber oak stands in southern Wisconsin[1]
(In stems per acre)

Plot	Gray dogwood	Hazel	Raspberry and blackberry	Gooseberry	Misc. species	All species
ALBANY WOODS (GREEN COUNTY)						
1-1	0	7,500	8,250	4,500	0	20,250
2-1	3,250	1,250	7,000	0	500	12,000
3-1	0	10,750	9,250	750	750	21,500
4-1	4,750	4,250	5,500	0	750	15,250
Stand average	2,000	5,938	7,500	1,313	500	17,250
COULEE EXPERIMENTAL FOREST (LA CROSSE COUNTY)						
1-1	5,875	3,750	4,625	3,875	5,250	23,375
2-1	5,125	500	2,125	2,250	1,375	11,375
3-1	625	0	4,000	4,875	250	9,750
4-1	2,750	500	4,500	1,375	125	9,250
Stand average	3,594	1,188	3,813	3,094	1,750	13,438

1/ 4 randomized blocks, each containing 4 1-acre-square plots, were established in each of these 2 oak stands. Results are based on 4 milacre quadrats randomly located in each 1-acre plot in the Albany Woods and 8 milacre quadrats in the Coulee Forest. These were the untreated control plots.

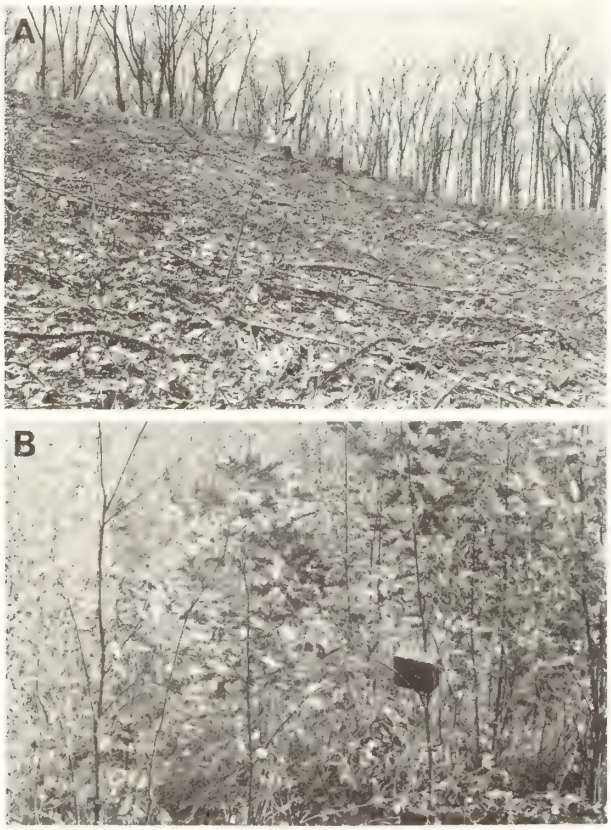

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FIGURE 10. — A, two-acre clear-cut area of oak sawtimber in east-central Wisconsin; B, same area 6 years later showing dense tree reproduction averaging 6 to 7 thousand stems per acre. About half of it is oak.

F-519100

FIGURE 11. — Dense thicket of mixed oak saplings that developed 12 to 15 years after clear cutting of the parent stand. This young growing stock is a mixture of stump coppice, seedlings, and seedling sprouts. Jackson County, Michigan.

The feasibility of the clear-cut method for regenerating small blocks of timber is frequently questioned. Yet, there are many ways of applying this method to regenerate individual oak stands to satisfy the desires of small woodland owners and to maintain esthetic values. Clear cuts can be made in groups, patches, or blocks of 1 acre or more over a period of years because all portions of the stand seldom mature at the same time; thus the total acreage cut each year can be controlled. Few oak stands, except those on poor sites and those that are overmature with few valuable trees left in the overstory, need to be harvested completely in one operation. Also, all oak stands need not be regenerated as soon as they reach merchantable size. Many owners may wish to harvest the periodic growth as long as operable cuts can be made.

Examples of the regrowth of oak following complete clear cutting are in evidence enough and the growing stock of sufficiently good quality to justify managing them for the next timber rotation (Fig. 11). It is apparent, too, that stump sprouts have been responsible for many of the present-day merchantable stands, even though they are stocked mostly with single trees in mixture with an occasional twin stem or "triplet" from a common root system (fig. 12). Multiple sprouts do not necessarily result in slow growth (Wood 1939).

Practically all studies of oak stands after various intensities of overstory cutting have reported abundant oak reproduction. However, this natural reproduction develops satisfactorily only where all the overstory trees are removed (Rudolph 1956; Scholz and DeVriend 1957; Merz and Boyce 1956; Minckler and Jensen 1959; Gammon, Rudolph, and Arend 1960; Bey 1964; Minckler and Woerheide 1965; McGee 1967).

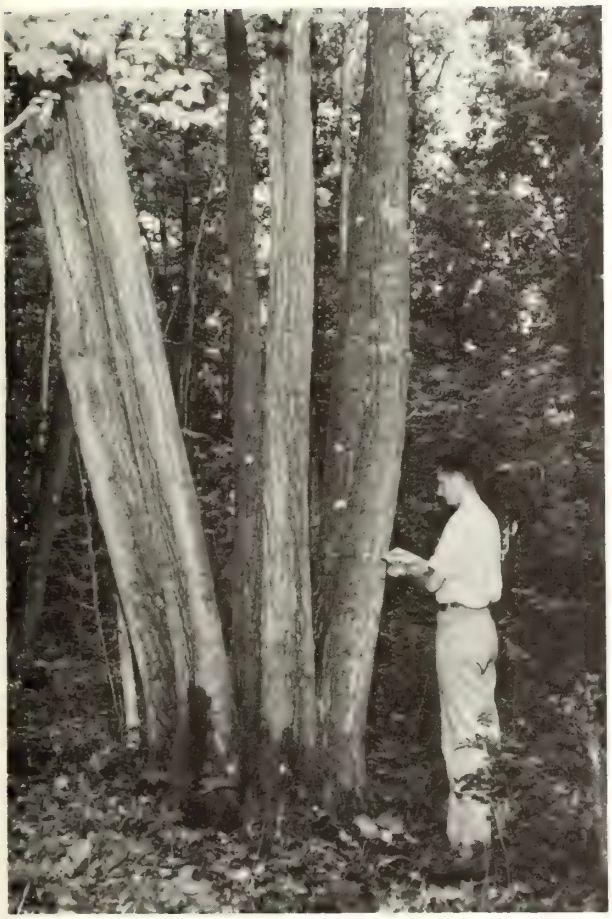

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FIGURE 12. — Six northern red oak sprouts 14 to 16 inches at d.b.h. and about 65 years in age. Normally only two or three stems would persist in a single clump for so long a period. The leaning character of the trees is typical of coppice from stumps. Clinton County, Michigan.

Complete clear cutting favored the best development of hardwood reproduction on more than 200 experimental plots in the central upland hardwoods of southern Illinois, southern Indiana, southeastern Ohio, and eastern Kentucky.[3] Six years after advance reproduction was knocked down by logging, new sprouts were more than twice as tall as stems of advance reproduction not killed back. New seedlings developed in the clear-cut areas after 2 years, but failed to compete successfully with the new sprouts. One acre was recommended as the minimum size for clear cutting; the maximum size will depend on local conditions, area of oak ready for harvesting, and desires of the owner.

[3] *Sander, I. L., and Clark, F. B. Reproduction of Upland hardwood forests in the Central States. (In preparation for publication, Northeast. Forest Exp. Sta., U.S.D.A. Forest Serv., Upper Darby, Penn.)*

Removing all the unmerchantable trees in clear cutting presents a costly and challenging problem (fig. 13). Any trees not knocked down or felled during logging should be cut or stem-injected with herbicides (table 9). In general, all trees over 2 inches d.b.h. should be removed.

Also, time and patience are needed in oak regeneration. For example, in the south central hardwoods, Sander and Clark[3] reported that all species, desirable and undesirable grow at about the same rate for the first 5 years after clear cutting. However, by the time the young stands reach 12 to 15 years of age, more desirable trees reach the dominant and codominant crown classes. Although no similar study of cutover oak stands has been conducted in the Lake States, general observations indicate that most of them are reasonably well stocked with desirable tree reproduction after 10 to 15 years.

Shelterwood Method

The shelterwood system, which is a series of partial cuts (normally three) to remove mature overstory trees, is usually recommended where desirable advance reproduction is inadequate to form a new stand. This condition may exist (1) where the overstory casts such a dense shade that seedlings and seedling sprouts of preferred species cannot survive, or (2) where they are present but are submerged in a brush understory.

In two shelterwood cutting studies in Wisconsin, we obtained adequate tree reproduction over a 14-year period by removing the overstory trees in three cuts. However, the results also indicated that removal of the overstory in two cuts would be even more practical. Not only was adequate oak reproduction obtained within 4 years after the first cut (nearly 3 thousand seedlings and seedling sprouts per acre), but high mortality and poor growth resulted from continuing the partial shade from a second partial cut. Also, the three cuts prolonged the rotation, resulting in increased cull and degrade losses to overmature overstory trees.

The first cut should remove one-third to one-half the basal area, leaving the best seed trees. The actual amount of overstory to remove will depend on the stand density and the abundance of the understory brush. When brush is scattered, the stand can be opened up to about 50 percent uniformly distributed crown cover. When brush is abundant, the forest floor should be left about 75 percent shaded by overstory trees, unless brush is first controlled by herbiciding or mowing. Trees left in the overstory should be dominants of desirable species that show evidence (old acorns on the ground) of being good seed producers. The cutting should be mainly from below. The principal oaks to favor for seed trees are northern red oak and white oak. If other valuable hardwoods such as white ash, basswood, and sugar maple are present

F-470320

FIGURE 13. — Sawtimber stand of oak on very good site (Miami silt loam) commercially clear cut for logs and veneer. Note number of unmerchantable trees left.

Table 9. — General herbicide prescription guides for killing pole-size hardwoods in the Lake States by spaced stem injections[1]
(In milliliters per injection)

Interval between injections (edge to edge) (inches)	Picloram mixture[2] (diluted 50/50 with water)	Undiluted amine salt 2,4,5-T or 2,4-D[3] (4 lb. a.e. gal.)	
	All seasons	Growing season	Dormant season
2	0.5-1.0	0.5	2.0
4	1.0-2.0	1.0	(4/)
6	2.0-4.0	4.0	(4/)

1/Large-crown dominant hardwoods, particularly sugar maple and white ash, are difficult to kill by spaced stem injections. These trees should be completely frill girdled by overlapping injections.

2/Contains 0.54 acid equivalent of 4 amine-3,5,6-trichloropicolinic acid and 2 pounds a.e. of 2,4-dichlorophenoxyacetic acid as the triisopropanolamine salt.

3/2,4-D amine is more effective than 2,4,5-T on most hardwoods except red maple.

4/Not recommended in dormant season.

and desired over oak on good sites, they too can be selected for seed trees. Red maple may qualify too, depending upon local soil and moisture conditions. Less commonly, yellow-poplar and black walnut may be left for the second (and final) harvest. When a choice must be made between seed trees, dominants and codominants with balanced crowns and apparent windfirmness should be reserved.

Special efforts should be made to knock down all ground cover and stir up the mineral soil. Litter over 1 inch in depth should be burned off or otherwise disturbed to expose the mineral soil. Herbicide treatments, disking, or rotary mowing might be needed to destroy the brush and encourage oak sprouts.

The final cut should be made immediately after the desired reproduction is obtained. Again, no attempt should be made to protect the advance reproduction in the final logging operation. The trampled and cut reproduction will sprout vigorously. Also, trees over 2 inches d.b.h. should be cut or killed.

Selection Method

The single-tree selection method of harvesting mature timber, which works so well for perpetuating certain tolerant hardwoods, is not feasible for regenerating mixed oak stands because the oak seedlings need full sunlight for best development. Selection cuttings periodically remove the mature trees at intervals ranging from 1 to 20 years. This stimulates the establishment of new seedlings, but the stand is not opened up enough for oak reproduction to develop successfully.

The disadvantages of the selection system for managing mixed oak were demonstrated on the Kaskaskia Experimental Forest in southern Illinois (Minckler, Plass, and Ryker 1961). Nine years of annual selective cutting reduced a 24-acre merchantable stand to one consisting mainly of saplings, poles, and small sawtimber. Annual cutting had to be discontinued because the small remaining trees did not grow fast enough to maintain periodic harvests.

Regeneration cutting experiments in southern Michigan also demonstrated that single tree selection was inferior to small-block clear cutting, group selection, and shelterwood cuttings that removed about 50 percent of the oak stand (Rudolph and Arnold 1956). Sander and Clark[3] reported that even 35 years after selection cutting, none of the reproduction had grown into pole-size trees, and that the stand looked the same as it did 5 years after cutting.

In previously unmanaged stands of oak, it is advisable to harvest the older or larger scattered trees of poor form, quality, or vigor that are crowding better trees at least 10 or more years prior to the final harvest cut (fig. 14). This, however, is an improvement cutting and thinning and should not be confused with a harvest cutting to regenerate the stand. Yet, such intermediate cuts in oak stimulate the establishment of advance reproduction that is needed when the final harvest cut is made 10 to 20 years later (Carvell and Tryon 1961, Ward 1966).

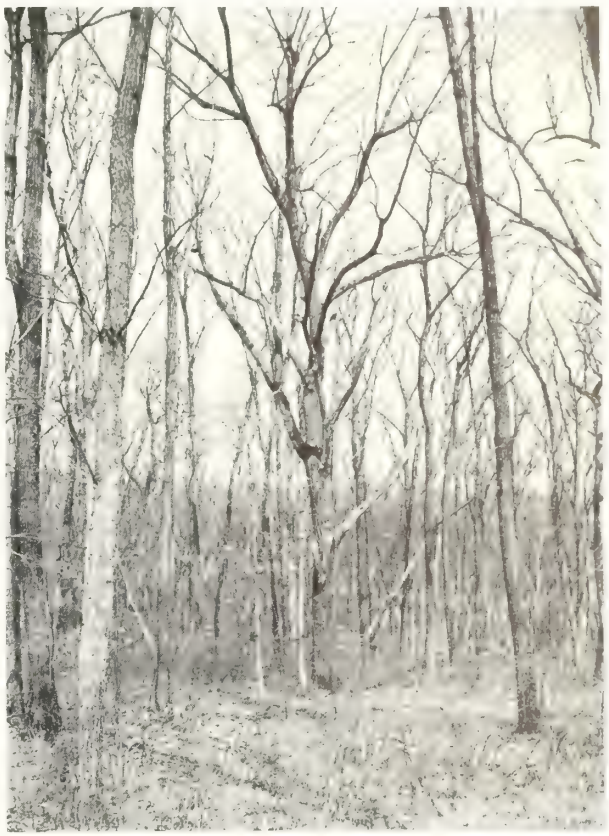

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FIGURE 14. — Unmanaged oak stands have many poor-quality trees that need to be removed by timber stand improvement and thinning operations. Note the large, limby northern red oak in the middle of this photo that is nearly worthless for timber, and is retarding the growth of many trees. Also note advance reproduction that is common in most oak stands.

Other Cultural Treatments

Questions are frequently asked about ground cover and soil treatments that might be tried to hasten oak regeneration and control brush. Many such treatments have been tried, with both positive and negative results.

Soil scarification. — Disking has been shown to increase the initial establishment of oak seedlings. Scholz (1955, 1959) found that disking and other soil disturbances greatly increased the number of red oak seedlings per acre in Wisconsin. He concluded that it was impractical from a cost standpoint because nearly the same quantity of oak reproduction was present after 10 or more years on both disked and undisked plots. However, disking to control brush and break up sod and deep litter to expose the mineral soil needs to be further explored, especially in open, understocked stands.

Burning. — Prescribed burning before regeneration cutting will consume deep litter and may provide a more favorable seedbed. However, our spring and fall burning trials before regeneration cutting on two experimental oak stands in Wisconsin failed to reduce brush. Burning immediately after clear cutting encourages oak to sprout from the base of stumps, reduces butt rot (Roth and Sleeth 1939), and also kills back the tops of advance reproduction and pole-size trees causing them to sprout vigorously. Prescribed burning techniques have not been perfected for the oak types; the elaborate precautions taken to prevent fires from escaping and causing extensive damage have kept costs high, but these can be reduced with experience. Of course, as soon as the quantity of oak reproduction is adequate, fire must be controlled.

Herbiciding. — Brush can be controlled by herbicide sprays. Before clear cutting two Wisconsin oak stands, we foliage-sprayed the brush with 2,4,5-T ester (about 1 lb. per acre) in midgrowing season using a portable mist blower. This killed back the ground cover temporarily, but a new crop developed in 2 years. If this treatment is used, however, we recommend foliage spraying as soon as the understory brush leafs out in May, just before the overstory leafs out. Most herbicides kill the desirable hardwoods as well as undesirable brush, and treatments cost $5 to $10 per acre.

Mowing. — Heavy rotary mowers also have possibilities for cutting back brush before regeneration cuts, especially where partial shelterwood cuttings are made to establish reproduction. Sprouts from the tree reproduction might outgrow the new brush crop. Mowing northern hardwood reproduction increased sprouting in New England (Jensen and Wilson 1951), but was considered impractical for this forest type.

ARTIFICIAL REGENERATION OF OAKS

Most of the oaks can be established artificially by planting either acorns or seedlings. Such plantings are normally made only to supplement natural reproduction in recent cutover oak stands on medium to good sites. A major reason why artificial regeneration of oak in the Lake States is seldom practiced is that for the same costs, hardwoods of greater value, such as black walnut, yellow-poplar, basswood, sugar maple, and white ash, can be planted. Nevertheless, there will be some medium to good quality sites where oaks, particularly red or white, may be desired.

Because oak seedlings require full sunlight for successful development does not mean that abandoned agricultural fields and old pastures are the best oak planting sites. Rather, the ideal sites will be recently logged sawtimber stands where all the trees have been taken off and open areas prevail (fig. 15).

F-519103

FIGURE 15. — Planting valuable hardwoods in bare openings of cutover oak stands.

Direct Seeding

The usual method of direct seeding is to plant the acorns an inch or two deep in mineral soil that has been exposed by scalping spots 1½ to 2 feet in diameter or by furrowing with a special plow (Sluder, Olson, and Jarrett 1961; Scholz 1964).

Species in the red and black oak group are somewhat easier to establish by planting acorns than those in the white oak group.

One of the problems in direct seeding white oaks is that the acorns must be collected and planted soon after they fall, because germination takes place in the autumn, often the driest season of the year in the Lake States region.

Rodents are the chief obstacle to reproducing oak by direct seeding (Bramble and Sharp 1949, Krajicek 1955). Various methods of control have been used to prevent or discourage pilfering of the seed. The most positive one is to cover the spots where the acorns are planted with protective screens of hardware cloth or some other material (Stoeckler and Scholz 1956). This procedure has proven effective throughout the eastern United States (Krajicek 1960; Sluder, Olson, and Jarrett 1961; Scholz 1964), but the costs are relatively high.

Damage may also be reduced by fall planting to get the acorns underground and out of sight of mice, chipmunks, and squirrels. This practice, in conjunction with screens, gave excellent results in the semihumid climate of North Carolina (Sluder 1964). In southeastern Ohio, fall-planted seed, including northern red oak acorns, also made the best showing (Plass 1952). Losses of acorns to rodents were lower with fall than with spring seeding in the Missouri Ozarks, but none of the various controls (season of planting, screening spots, or use of repellents) were good enough to be recommended for general use (Nichols 1954). Until satisfactory rodent control methods are developed, direct seeding of the oaks cannot be recommended as a standard practice.

Planting

Oak seedlings may be grown in a nursery and field planted as 1-0 or 2-0 stock. This method is more expensive than direct seeding but it assures better initial establishment of the seedlings. The trees should be planted where they will receive nearly full sunlight and on sites of at least medium quality.

Rabbits and other rodents often girdle or clip off the tops of the young trees. This damage can be curtailed by reducing the rodent population, planting when it is naturally low, or by wrapping the stems with a protective cover.

We hand-planted northern red oak, yellow-poplar, white ash, black walnut, basswood, sugar maple, and red maple seedlings in two locations after complete clear cutting in southern Wisconsin. The initial survival after 2 years was about 90 percent. Height growth averaged nearly 20 inches per year for all species except northern red oak, which averaged only about 5 inches per year.

INTERMEDIATE CUTTINGS

Even after oak regeneration is established, additional treatments will be needed to ensure that enough young trees of desirable species and quality are free to grow. Such treatments may include weeding and cleaning, liberation cutting, thinning, and pruning of selected trees. Because the cost of these treatments is incurred long before harvest cuttings are made, prudent management requires that the potential investment costs (plus interest) be weighed against the expected returns. Intensive management will seldom be profitable on poor sites, so costly cultural practices should be limited to those oak sites where faster growth rates and higher quality trees can be expected.

Fortunately, few young stands will need all the above treatments. The basic objective in oak management on good sites is to produce about 100 high-quality sawtimber trees per acre in the shortest possible time. Since it is nearly impossible to select final sawtimber crop trees 60 to 80 years in advance of maturity, additional trees must be carried through the rotation as insurance against loss or damage.

Weeding and Cleaning

Weeding and cleaning are carried out in stands not past sapling size to remove stems that are competing with potential crop trees. Eliminating undesirable species and poorly formed stems would be most desirable when the trees are 3 to 4 feet tall. However, releasing about 200 to 300 selected saplings per acre when they are 16 to 20 feet tall is more practical. At this time the main job is to weed out undesirable species or poorly formed trees that are crowding or suppressing potential crop trees.

The initial dominance of oak regeneration has an important effect on its future growth rate. In a 5-year period beginning 4 years after clear cutting of the parent stand, released dominant oaks made double the height growth of unreleased ones, but intermediate and suppressed trees failed to respond to this treatment (Walters 1963).

Do not attempt to eliminate all undesirable stems in sapling stands. It is too costly and will do more harm than good, because the released trees will develop excessively branchy crowns. Instead, select potential crop trees on about a 15-foot spacing, and release them by killing adjacent stems within a radius equal to half the tree's height. This spacing of crop trees and degree of release should provide acceptable stocking by the time the trees average 4 to 5 inches d.b.h. Also, do not select trees that have suppressed or intermediate crowns for crop trees just to maintain adequate spacing, because such trees grow slowly even after release. The 15-foot spacing figure is only a guide; some crop trees may be closer and others farther apart.

Species to be favored in weeding and cleaning include high-quality oaks, white ash, American basswood, black cherry, yellow-poplar, butternut, and black walnut. Trees to be removed include poorly formed trees of all species, and so-called "weed species" such as eastern hophornbeam (ironwood) and American hornbeam (blue beech). Also, any species found on a site too poor for its best development could be considered a weed species, although it might be acceptable when grown on a suitable site. Red maple is a classic example of such a tree, and to a lesser degree, so is sugar maple.

Trees eliminated in cleaning may be cut or killed by herbicide injections. Basal sprouts that may develop later will create no problem because the released trees are tall enough to maintain their height advantage over any new shoots. The principal disadvantage of cutting and felling medium-to-large saplings (trees 20 or more feet tall) is the labor required; use of a tree injector usually is cheaper. The number of trees that must be treated per acre seldom requires more than 1 man-day to complete the job.

Cleaning can be done faster by using herbicides in tree injectors. Several makes of tree injectors are on the market, and the particular one used will be a matter of personal choice. A hypohatchet, which applies the herbicide at a convenient chopping height, is faster and less tiring than an injector. An ordinary hatchet can also be used to make cuts through the bark, and a plastic squeeze bottle or a small oil can to apply the herbicide. Several herbicides can be used effectively in tree injectors; their prescriptions vary by species and tree size (table 9).

Liberation Cutting

Liberation cuttings are made to free young trees not past the sapling stage from the competition of older, overtopping trees (Smith 1962). This type of cutting will be required in many oak stands where successful hardwood reproduction has developed in the openings created by heavy cutting (fig. 16). The scattered older trees are usually not numerous enough or of sufficient value to justify leaving them for another harvest cut. Where these stand conditions exist, the liberation cutting should be made promptly to release the reproduction and minimize damage caused by felling or girdling of the large overstory trees.

Whenever possible, such overstory trees should be cut and utilized. Even when they cannot be utilized, it may be desirable to cut them for esthetic or safety purposes along roads and around forest recreation areas. Where esthetic values are not a consideration, unmerchantable overstory trees can be girdled injected with herbicides and allowed to slowly deteriorate.

F-519104

FIGURE 16. — This stand was commercially clear cut leaving many unmerchantable trees. Abundant reproduction has developed, but it will be retarded unless a liberation cut is made.

Improvement Cutting and Thinning

Improvement cuttings are made in stands past the sapling stage for the purpose of improving species composition and stem quality by removing trees of undesirable form and species from the main canopy (Smith 1962). Thinnings, on the other hand, are made in immature stands for the purpose of stimulating growth of the remaining trees, to shorten the rotation, and to increase the total yield of useful timber products from the stand. Surplus trees are removed to concentrate potential wood production on a limited number of selected crop trees (Smith 1962). Although the specific objectives of improvement cuttings and thinnings are different, few unmanaged oak stands contain surplus high-quality trees. The principal job will be removing less valuable trees until a desired stand density is reached. This can be accomplished by a combined improvement cutting and thinning operation.

Several studies have shown the growth response of crop trees following improvement cutting and thinning in oak stands. In southern Illinois, growth of pole-size white oak trees the year after release was 41 percent greater than average growth for the previous 10 years (Minckler 1967). And their growth was 46 percent greater than that of unreleased trees in the stand. The growth response of individual trees was not influenced by age for trees 35 to 100 years old. The smaller crown class trees (codominant and less in size) continued to accelerate in growth the second year after release.

In two southern Michigan oak stands, the board-foot growth in the 10 years following an improvement cut was 20 percent greater than on the control plots (Arend and Monroe 1950). In West Virginia, Carvell (1964) made a series of three improvement cuts over an 11-year period in immature

mixed hardwoods, favoring the 100 trees per acre most promising for quality saw logs. After three improvement cuts, 354 trees per acre totaling 7.8 cords had been cut and sold. The remaining volume was still equal to that in the control area where no improvement cuts were made. In addition, the remaining thinned trees were about 1 inch larger in diameter.

Most improvement cuttings and thinnings are made periodically to maintain rapid growth of the most desirable trees. For oaks, the "stop thinning" age is about 60 to 70 years on medium sites and less on better sites (U.S.D.A. Forest Service 1962), provided the stand has been properly managed. In unmanaged stands, improvement cuttings and thinnings may be useful even at later ages on good sites.

All trees left for sawtimber in oak stands should have straight, clear, nearly defect-free stems for at least 10 feet and preferably 16 to 20 or more feet in height, and well balanced crowns that make up 30 to 50 percent of the total tree height. Species to favor in addition to northern red and white oak include black walnut, butternut, red maple, yellow-poplar, sugar maple, basswood, white ash, and black cherry. Hickories have had a lower value in the past than most hardwoods, but this is changing. In addition, hickories have some excellent multiple-use qualities, such as producing nuts for animal and human consumption and improving soil by virtue of the high calcium content of their foliage (Lutz and Chandler 1946).

One of the problems apparently related to thinnings and improvement cuttings in oak is epicormic branching. In a study of old-growth Appalachian hardwoods, Jemison and Schumacher (1948) found that many trees develped new sprouts after the stands were partially cut. Dense stands that were heavily cut showed the highest incidence of postlogging sprouting.

In southeastern Iowa, examination of the butt logs of 600 white and black oaks after thinning in 25-to 50-year-old stands showed a higher incidence of epicormic branching to be associated with these factors: low residual stocking, sprout clumps, and suppressed, intermediate, and codominant crown classes (Brinkman 1955). White oaks that became dominant due to thinning developed epicormic sprouts on the butt log more frequently than those that were dominant prior to cutting. The lowest residual stocking gave the best diameter growth, but at the cost of more epicormic branches and potentially lower quality.

Another study in south-central Iowa confirmed that dominant white oaks have fewer epicormic branches than those in other crown classes (Krajicek 1959). Examination of 400 trees (100 each for suppressed, intermediate, codominant, and dominant crown classes) showed that dominant trees had the fewest epicormic branches, the highest number of clear log-faces, and other quality advantages. Thus, it seems advisable to favor dominant trees when making intermediate cuttings in white oak stands.

Little information on epicormic branching of northern red oak can be found in the forestry literature. However, we have observed "feathering out" of this species in heavily thinned stands that are slow in closing the crown canopy. Black oak is probably worse in this respect than northern red oak, which has excellent natural pruning tendencies.

The problem of epicormic sprouting is more critical in younger stands because the trees are smaller and the branches will have a longer period to develop into major defects before a final harvest is made. In general, thinnings should favor single-stemmed dominant trees and maintain stocking levels as high as possible without adversely affecting the volume growth of these trees.

Pruning

The pruning of deciduous trees is still in an experimental stage in the United States. This is understandable because there has been an exploitable supply of good hardwoods in natural stands throughout most of the eastern half of the country during the past 30 to 40 years. Consequently, most foresters and interested landowners have doubted that pruning was a sound economic investment. However, the future outlook in unmanaged stands is for declining timber quality, and this prospect may justify future financial investment in pruning.

Several hardwood pruning studies have been made. In West Virginia, selected trees in a stand of mixed oak 6 to 12 inches d.b.h. were pruned during the months of January, April, July, and August to a height of 17 feet. Ten years later these oaks were cut, and the pruning wounds were dissected and analyzed. One conclusion was that the vigor of the pruned trees, rather than the season when the work was done, seemed to be the important factor in healing (Roth 1948). Also, pruning scars wider than 1.5 inches at the time of treatment were more likely to develop decay than smaller scars. Sprouting was so profuse on the boles of pruned white oak that a question was raised as to the advisability of pruning this species.

However, in another white oak pruning study in southern Illionois, Minckler (1967) reported that a combination of release and pruning of crop trees can fulfill the need for high-quality white oak in the near future. He found that 72 percent of the pole-size white oaks with one to three branches pruned in the first 17 feet were still clear after 10 years. Trees with an average of eight live branches pruned in this zone had an average of two new sprouts 10 years later. Therefore, dominant white oaks with only a few branches might be successfully pruned to maintain clear logs.

In another white oak pruning study made by Boyce and Neebe (1963), trees 3⅓ to 5 inches d.b.h. were pruned to a height of 17 feet. The stems were coated with a variety of sprout-inhibitors during both the dormant and growing seasons. The most effective control for stem sprouts on white oak was SAE 20W oil applied with a brush. On trees given this treatment, an average of only 2.5 sprouts per 17 feet of pruned bole developed by the end of 4 years compared to 10.5 sprouts for untreated trees. When the oil was applied during the dormant season, damage to white oak was slight; black oaks, however, were injured by this treatment regardless of season.

A pruning study on pin oak in southeastern Missouri provided some additional information on bole sprouts (Minckler and Krajicek 1964). A total of 150 dominant and codominant trees 6 to 10 inches d.b.h. were pruned to a height of 17 feet in March, June, and October 1957. Cuts were made flush with the bole with a pole pruning saw. No effort was made to cut into the branch callus, although this often happened. Half of all sample trees, including controls, were exposed to direct sunlight on the south and southwest sides by cutting adjacent trees. Prior to pruning there was an average of 20 small (less than ½ inch in diameter) branches per tree, 13 medium (½ to 1 inch), and 2.4 large (more than 1 inch). Season of pruning had little effect on the number of new branches. The average butt log had 36 bole branches initially, and 4 years after pruning there were only 7. Of these, five were less than 12 inches in length and two were already dead. New branches were concentrated on the exposed faces, and they were twice as long as those on the shaded faces. Trees with the most branches initially developed the most new branches. After 4 years, 96 percent of the pruning wounds were healed over.

In summary, it appears that limited artificial pruning may have practical application in oak stands. Recommendations are as follows:

1. Prune only well formed, vigorous, dominant trees 5 to 8 inches d.b.h. where removal of a few branches can produce a clear log. (Stems that support numerous branches along the bole can seldom be successfully pruned artificially.)

2. Saw off the branches flush with the stem. The low ridge of callus around the branches may be cut through, but no special effort need be made to do this as in pine. Branches up to 3 inches have been reported completely healed over in 4 years (with little risk of rot).

3. Avoid pruning branchy oaks.

4. Provide adequate crown growing space for pruned trees, but avoid excessive exposure of the stems to direct sunlight.

The removal of a few branches from vigorous, dominant oaks may upgrade many future saw logs. When done in this way, artificial pruning of oaks and associated valuable hardwoods may be profitable.

GROWTH AND YIELD

Growth of individual trees and stands, and yield of well stocked oak forests in the Lake States, have been studied by several investigators over the past 40 years (Kittredge and Chittenden 1929, Schnur 1937, Gevorkiantz and Scholz 1948, Gysel and Arend 1953). Periodic growth has also been measured in several sawtimber stands. Considerable growth and yield data are available for evaluating the productivity of unmanaged oak stands on various sites, but only scant information is available for evaluating the growth potential of oak stands under intensive management.

Periodic Annual Growth

Medium to Good Sites

In the Lake States, well stocked, unmanaged stands of mixed oak sawtimber on medium to good sites will produce an average net periodic annual growth of about 200 board feet per acre. This amount will vary considerably because of differences in individual tree vigor, tree age and size, stand structure, and site.

In southern Michigan (Livingston County), the 10-year periodic net annual growth in four mixed oak farm woodlands ranged from 128 to 268 board feet per acre, averaging 205 board feet (table 10). These stands were fairly well stocked (86 square feet of basal area per acre) and growing on medium to good sites. Cutting and grazing were excluded during the 10-year period.

In Wisconsin, maximum volume growth rates for well stocked mixed oak stands were reached between 60 and 80 years of age (Gevorkiantz and Scholz 1948). Average annual growth was 275 board feet per acre on medium sites and 290 feet on good sites. In the ensuing 20-year period, however, volume growth on these sites dropped to 170 and 190 board feet per acre, respectively.

Poor Sites

Few studies have been made of the growth of oak stands on poor sites that once supported pine. Kittredge and Chittenden (1929) reported periodic annual growth for average stands 40 to 60 years old to be about 18 cubic feet per acre. In well stocked stands of the same age it averaged 30 cubic feet per acre.

More recently, Arend (1964) measured the 11-year growth of mixed oak stands on former pine sites in northern Lower Michigan. On Grayling sand the periodic annual growth averaged 29.8 cubic feet per acre (0.38 cord) in six 40- to 60-year-old stands with stocking about 55 square feet basal area. On Rubicon sand, which is a somewhat more productive soil, the periodic annual growth was about 42 cubic feet or nearly 0.6 cord per acre for stands 60 to 70 years old. These data indicate that unmanaged oak stands on poor sites in Lower Michigan are producing from 30 to 40 cubic feet or 0.4 to 0.6 cord of merchantable pulpwood per acre each year.

Table 10. — Volume and growth per acre of mixed oak stands, Livingston, County, Michigan[1]

Farm woodlot	Average stand age 1949	Estimated net volume[2] 1939	Estimated net volume[2] 1949	Mean periodic annual growth: Ingrowth	Mean periodic annual growth: Saw log trees 1939	Mean periodic annual growth: Total
	Years	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
Robinson	70	4,432	6,268	23	161	184
Kerber	80	4,636	7,020	49	189	238
Salmon	70	4,576	7,256	47	221	268
Miller	85	7,608	8,888	15	113	128
Average	76	5,313	7,358	34	171	205

[1] From Lake States Forest Exp. Sta. Tech. Note 327 (Arend, Gunderson, and Monroe 1950).

[2] International 1/4-inch log rule.

Yield

Projected oak yields for various ages, stocking, and sites have been made in Wisconsin by Gevorkiantz and Scholz (1948) and in the eastern oak region by Schnur (1937). The expected yields from such oak stands for normal or full stocking are presented in table 11.

The average yields of the best unmanaged stands at age 80 in southern Michigan ranged from 900 to 2,500 board feet per acre on poor sites, and from 11,000 to nearly 20,000 board feet on good sites (table 12). Two oak sawtimber stands, which are remnants of the presettlement forests in southern Michigan, contained 25,000 board feet per acre in 1952. However, few such stands remain.

Effect of Stocking or Stand Density

Total growth and yield per acre on a given site are similar over a fairly broad range of stand density. This is the stocking range where the trees are able to effectively utilize the available growing space. However, the stocking within this range does affect the stem taper and the diameter growth of individual trees, and these characteristics have an important effect on the final products. Therefore, it is difficult to define "optimum" stocking without knowing the management objectives. If the objective is oak sawtimber, table 13 can be used as a guide for determining the number of trees and basal area that well stocked stands of different sizes should contain.

Importance of Tree Vigor and Quality

The expected growth and yield from unmanaged oak stands have been presented without reference to the growth performance of individual trees. Species has some effect on individual tree growth; for example, northern red oak is generally the fastest growing oak in the Lake States. However, when the net growth rates of different oak species are compared on the same site for trees having similar crowns, stems, age, and position in the stand canopy, species differences are not too important (table 14). Oak species also vary greatly in their longevity and adaptability to different site conditions, and in their value for different wood products. All of these factors must be considered in deciding which tree to favor in timber management.

A 12-year study in southern Michigan (Washtenaw County) showed the effects of crown and stem characteristics on the net growth of individual trees. When this study was started, the stand was about 90 years old, had a total net volume of 6,886 board feet per acre (International ¼-Inch Log Rule), and 90 square feet of basal area in trees 5 inches d.b.h. and larger. The stand was fully stocked, and the site was medium to good. The species composition was 33 percent black oak, 31 percent white oak, 18 percent northern red oak, 16 percent hickory, and 2 percent other species, such as red maple.

The individual trees were classified by management potential both at the beginning and the end of the study as follows:

Good. —

a. Straight stems with less than 10 percent sweep.

b. Clear bole or other having a No. 1 or better log potential for 16 or more feet.

c. Merchantable species.

d. Balanced crown occupying one-third to one-half the total height.

e. Less than 10 percent cull defect in the main stem.

Poor. —

a. Crook or forking in the main stem to restrict potential log length to less than 16 feet.

b. Species difficult to sell.

c. Crown less than one-third height or otherwise limited in size.

d. Cull and defect in main stem exceeding 25 percent.

Fair. — Trees not meeting the obvious "good" and "poor" management potential requirements were classed as "fair."

The individual tree class ratings changed very little during the 12 years. The "poor" tree class suffered the most mortality. Average stand growth during the study was 247 board feet per acre per year.

Table 11. — Comparison of reported yields for upland oaks

Site designation		Average stand age	Volume per acre[1]					
Wisconsin	Eastern Region		Wisconsin[2]			Eastern Region[3]		
		Years	Cu. ft.	Cords	Bd. ft.	Cu. ft.	Cords	Bd. ft.
Very poor site	Very poor site (SI 40)	20	480	--	--	485	--	--
		40	1,050	10	--	1,030	8.0	50
		60	1,555	19	550	1,540	16.7	400
		80	2,000	25	2,500	1,975	24.1	1,450
		100	2,350	29	4,550	2,375	30.5	3,350
Poor site	Poor site (SI 50)	20	650	1	--	635	.8	--
		40	1,350	15	--	1,360	12.8	150
		60	1,950	25	2,300	2,050	24.5	1,100
		80	2,550	32	6,400	2,635	34.1	4,000
		100	3,050	38	9,600	3,140	41.4	7,750
Medium site	Average site (SI 60)	20	850	2	--	805	2.0	--
		40	1,750	21	300	1,725	18.6	500
		60	2,550	33	4,700	2,590	32.9	3,150
		80	3,300	41	10,200	3,325	43.9	8,350
		100	3,900	49	13,600	3,970	52.7	13,700
Good site	Good site (SI 70)	20	1,000	3	--	975	4.2	--
		40	2,050	25	1,600	2,075	24.6	1,100
		60	3,050	39	7,600	3,115	40.9	6,700
		80	3,950	50	13,400	4,000	53.1	14,100
		100	4,700	59	17,200	4,780	63.5	19,900
Very good site	Excellent site (SI 80)	20	1,150	4	--	1,145	7.3	--
		40	2,400	30	2,800	2,440	30.7	2,500
		60	3,600	46	10,500	3,690	48.9	11,350
		80	4,600	59	16,800	4,725	62.8	19,700
		100	5,500	69	21,100	5,650	75.1	26,100

[1] Cubic foot volume based on entire stem inside bark; cord volume based on all merchantable stemwood to a 4-inch top outside bark; board foot volume based on Scribner Rule to a minimum top diameter of 8.0 inches inside bark.

[2] From Wis. Conserv. Dep. Public. 521 (Gevorkiantz and Scholz 1948).

[3] From U.S. Dep. Agr. Tech. Bull. 560 (Schnur 1937).

Table 12. — Yields of well-stocked unmanaged mixed oak stands in southern Michigan at 80 years[1]

VERY POOR SITES

D.b.h. class (inches)	Total trees of all species	Basal area	Per acre volume[2]		
	Number per acre	Sq. ft. per acre	Cu. ft.	Cords	Bd. ft.
5-10	194	59.7	838	10.5	900
11-13	36	27.9	432	5.4	
Total	200	87.6	1,270	15.9	
POOR SITES					
5-10	174	53.9	765	9.6	2,535
11-15	59	47.3	1,003	12.5	
Total	233	101.2	1,768	22.1	
MEDIUM SITES					
5-10	89	29.4	475	5.9	
11-22	81	86.5	1,944	24.3	5,650
Total	170	115.9	2,419	30.2	
GOOD SITES					
5-10	81	21.7	414	5.2	
11-25	88	107.7	3,080	38.5	11,440
Total	169	129.4	3,494	43.7	
VERY GOOD SITES					
5-10	55	17.4	378	4.7	
11-24	95	125.4	5,130	64.1	19,950
Total	150	142.8	5,508	68.8	

[1] Adapted from Mich. Agr. Exp. Sta. Tech. Bull. 236 (Gysel and Arend 1953).

[2] Cubic foot volume based on main stem, less bark; cord volume based on all merchantable wood to a 4-inch top, outside bark; board foot volume by International 1/4-inch log rule.

How did the individual trees perform over the 12-year period? The trees classed as having "good" management potential, representing only one-third of the stocking, produced 168 board feet on the average or over two-thirds of the total annual growth. Trees in the "poor" management potential class, representing nearly one-half the total growing stock, produced less than 10 per cent of the growth. On a per-tree basis, the weighted average growth was 5.6 board feet per year for "good" trees versus 1.0 board foot per year for "poor" trees (table 14).

If the "poor" management potential trees could have been removed 10 to 15 years prior to this growth study, leaving a basal area of about 60 square feet per acre, the subsequent growth would have been concentrated on the taller, straighter trees, which are capable of producing the greatest volume of usable timber.

This emphasizes the importance of improvement cuttings in our presently unmanaged oak stands. By favoring the "good" and "fair" potential trees, it seems reasonable that the prevailing 200 board feet per acre per year now being produced by fully stocked stands on medium to good sites could be at least doubled (fig. 17).

Table 13. — Acceptable range in stocking for managed mixed oak stands in the Lake States Region[1]

Average tree diameter[2] (inches d.b.h.)	Trees per acre[3]	Basal area per acre
	Number	Sq. ft.
3	775-1430	38- 70
4	530- 930	46- 81
5	380- 655	52- 89
6	285- 495	56- 97
7	220- 385	59-103
8	180- 305	63-107
9	145- 255	65-112
10	125- 210	67-115
11	105- 180	69-118
12	90- 155	71-122
13	80- 135	73-124
14	70- 120	74-126
15	60- 105	75-128

[1] Adapted from Forest Sci. 13: 38-53 (S. F. Gingrich 1967). These figures appear high for saplings--200 to 300 per acre are normally adequate. The minimum ranges could be considered adequate after thinning and maximum ranges would indicate need for thinning.

[2] Includes all trees 2 inches d.b.h. and larger.

[3] The maximum values correspond closely to what Schnur (1937) considered necessary for 100-percent stocking, and the minimum values correspond closely to what he considered 50-percent stocking.

F-519105

FIGURE 17. — Well-managed oak stand in southern Michigan. Periodic improvement cuts and thinnings have been made for previous 20 years.

MANAGING OAK LAND FOR MAXIMUM RETURNS

Forest land is not always owned or acquired solely for timber production. Some people have forest land for outdoor recreation, pride of ownership, or for investment purposes.

Although much of the oak in the northern Lake States is publicly owned, most of the oak in the southern portion (where the greater share of the oak area is found) is privately owned. Whatever the owner's objectives, he might still like to know what the potential revenues from managing and harvesting this timber would be. The following discussion presents guidelines for the forest owner who is interested in managing his oak lands for timber production.

Table 14. — Effect of species and potential stem quality on periodic annual growth rate in a southern Michigan mixed oak stand[1]

Management potential class	Net periodic annual growth per tree[2]						Net periodic annual growth per acre, all species
	Northern red oak	Black oak	White oak	Hickory	All species		
	Bd. ft.				Bd. ft.	Cu. ft.	Bd. ft.
Good	6.3	5.2	5.8	5.4	5.6	0.9	168
Fair	4.7	4.0	2.3	2.9	3.4	.5	60
Poor	-2.5	1.7	1.2	-.1	1.0	.3	19

[1] Based on growth of trees 5.0 inches d.b.h. and larger over a 12-year period after the stand reached 90 years of age.
[2] International 1/4-inch log rule.

Although silvicultural practices can maximize timber yields for any particular stand, the profitability of management is limited by site productivity and present stand condition. Because site influences species composition, growth rate, tree quality, and regeneration potential, site productivity is the key to oak management decisions (figs. 18, 19). For example, growing oak on poor sites over a full rotation cannot be justified solely for the timber value. Yields are not high enough at present prices to offset accumulated costs of ownership plus interest. Although harder to regenerate, the best oak sites can produce high-quality sawtimber and veneer logs, which bring the highest stumpage prices.

F-470321

FIGURE 18. — White oak veneer logs cut from mixed oak on good site in Ionia County, Michigan. Note bare condition of soil. Dense reproduction developed after the clear cutting.

The other factor limiting profitability — present stand condition — is determined largely by age of the main stand and stocking. Stand age largely determines tree size, value, vigor, and response to thinnings and release. It is also important in evaluating net financial return from a specific stand treatment. Stocking is important because yields in understocked stands will be low regardless of the productivity of the site, and tree quality may be poorer.

F-519102

FIGURE 19. — Clear cutting oak for pulpwood on poor sites in northern Lower Michigan (Grayling sand). This stand averaged about 10 cords per acre at age 65 years. Note the number of small trees left after commercial pulpwood cutting.

Medium to Good Oak Sites

(Sites Where the Largest Oaks Are 65 to 80 Feet Tall at 50 Years)

On the more productive oak sites (table 5), oaks and associated hardwoods can be managed for high-quality sawtimber. High-quality saw logs and veneer are the most profitable oak timber products; Grade 1 logs sell for twice as much as Grade 2 logs, and Grade 3 logs can seldom be harvested at a profit. Seldom will it be advisable to convert oaks to conifers on good sites, because conifers cannot compete successfully with hardwoods on highly productive sites.

Well Stocked Stands

Sawtimber stands. — Young, well stocked sawtimber stands, especially those having no previous management, will require improvement cuttings and thinnings to remove the many poorly formed, low-value trees and to provide adequate growing space for the best potential crop trees (table 13). This practice will also stimulate establishment of the oak reproduction essential for regenerating the stand. These stands will rank highest in work priority on the basis of return on the investment in silvicultural work (Herrick and Morse 1968). Generally, the trees that need to be removed can be sold. This will include some of the larger mature trees that are common in unmanaged stands of sawtimber size. Large culls and other unmerchantable trees that are occupying valuable growing space can be killed with herbicides (table 9). These improvement and partial harvest cuttings can be carried out periodically as long as operable cuts can be made, depending on the specific condition of each stand and the desires of the owner. All trees should be removed in the final harvest cut in order to regenerate the stand, provided adequate advance reproduction is present. Normally this will be no problem in managed stands.

Poletimber stands. — These stands will require timber stand improvement to remove poor-quality trees and to release about 100 potential crop trees per acre to keep them growing rapidly. Where a market exists for pulpwood, most trees removed from pole-size stands can be sold. When no such market exists, about 100 potential crop trees per acre should be maintained in a free-growing condition by poisoning the competitors. Also, pruning some of the potential crop trees is desirable if they have a few scattered branches in the first 16-foot log.

Seedling and sapling stands. — Weeding and cleaning are desirable to keep the best 200 to 300 trees per acre from being suppressed and to shorten the rotation. However, costs need to be kept low because of the long waiting period before the released trees can be harvested. Compared to poletimber and sawtimber stands, these stands will rate low in work priority based on return on silvicultural investment.

Poorly Stocked Stands

These are stands that are considered 50 percent or less stocked for their age.

Sawtimber and poletimber stands. — When oak stands of this size are poorly stocked, about all that can be done is to wait until the trees can be harvested and a new stand established. Some timber stand improvement work may be undertaken to control large culls or other undesirable trees that are suppressing valuable trees. Also, where removing a few limbs will produce Grade 1 logs, trees should be pruned.

Seedling and sapling size stands. — The way these stands should be handled depends on their stocking. If the stocking will eventually produce an operable crop of poletimber or sawtimber trees, no immediate attention is required. However, thinning and pruning can be considered as the stand develops.

If the stand is too poorly stocked to produce an operable crop of timber, planting may be needed to increase the stocking. On suitable sites, stocking can be increased by planting fast-growing, high-value species such as black walnut, yellow-poplar, white ash, basswood, and maple. Planting oak will seldom be advisable because sprouts are normally scattered throughout the stand and planted oak seedlings grow slowly.

Good oak sites are seldom understocked for long in the seedling and sapling stages. Light-seeded tree species quickly invade the openings. Burning will kill back existing reproduction to a common age, stimulating more vigorous sprouting and providing a favorable seedbed for light-seeded species. Thus, on sites where adequate natural reproduction can be expected in a reasonable time period, few costs can be justified to improve the stocking.

Poor to Medium Sites

(Sites Where the Largest Oaks Are 40 to 60 Feet Tall at 50 Years)

These oak stands should either be managed for oak pulpwood or converted to pine, because high-quality sawtimber is difficult to produce on such sites. The choice depends on many factors, such as existing oak stocking, site productivity, desires of the owner, available capital, annual costs, rate of return expected on the capital investment, oak and pine stumpage prices, and possible returns from hunting and other outdoor recreation.

Managing for oak timber production alone on poor and medium sites is not profitable. In fact, even if annual costs total as little as 50 cents per acre over the rotation, fully stocked oak stands at

40 years would show a minus net worth (table 15). Even with no annual costs (and this is unrealistic) these oak stands would yield only a few dollars per acre. Therefore, supplemental income from hunting rights or other outdoor recreational uses of the land is needed to meet costs of ownership. With such an additional source of income, producing oak timber on these sites can be made profitable.

Table 15. — Present worth of oak stands managed for oak timber on poor and medium sites at 4 percent interest[1]
(In dollars per acre)

Rotation length (years)	Stocking percent	Present worth of timber when annual costs are			
		$ 0.00 per acre		$ 0.50 per acre	
		Pulp	Logs	Pulp	Logs
POOR SITES (SI 50)					
40	100	4.08	--	-12.01	--
	75	3.05	--	-13.04	--
	50	2.03	--	-14.07	--
	25	1.00	--	-15.09	--
60	100	3.39	1.36	-13.76	-15.79
	75	2.54	1.01	-14.61	-16.13
	50	1.68	.67	-15.47	-16.48
	25	.83	.32	-16.32	-16.62
80	100	2.07	2.42	-15.75	-15.39
	75	1.55	1.81	-16.27	-16.01
	50	1.02	1.20	-16.80	-16.83
	25	.50	.59	-17.32	-17.23
MEDIUM SITES (SI 60)					
40	100	6.29	--	-9.81	--
	75	4.71	--	-11.38	--
	50	3.13	--	-12.96	--
	25	1.55	--	-14.54	--
60	100	4.48	3.95	-12.67	-13.20
	75	3.35	2.95	-13.79	-14.20
	50	2.23	1.96	-14.92	-15.19
	25	1.10	.97	-16.05	-16.18
80	100	2.77	5.09	-15.05	-12.73
	75	2.07	3.81	-15.75	-14.01
	50	1.37	2.53	-16.45	-15.29
	25	.67	1.25	-17.14	-16.56

[1] Oak yields from U.S. Dep. Agr. Tech. Bull. 560 (see table 11). Stumpage prices used were $1.00 per cord for pulpwood and $7.50 per M for sawtimber. These were increased annually by 0.5 percent for pulpwood and 1 percent for sawtimber.

Small Sawtimber and Poletimber Stands — All Stockings

In oak stands where trees are approaching pole size (5 inches and larger at d.b.h.), the best policy is to wait until the existing trees can be harvested. Thinning costs cannot be justified with present costs and stumpage values. As soon as a harvest cut can be made, the stand should be clear cut. On poor sites, pulpwood yields of 25 to 30 cords per acre can be expected in fully stocked stands at age 60 to 80 years. On medium sites, 30 to 40 cords per acre can be expected for stands of similar age and stocking (table 11). Medium sites may also produce some board foot volume at age 60 to 80 years.

Seedling and Sapling Stands — All Stockings

When the stand consists of reproduction on poor and medium sites, the owner has several management alternatives to consider. These alternatives are nearly the same ones that exist immediately after clear cutting. The choice will depend on the age and stocking of the oak stand. If the stand is well stocked with saplings, the owner may decide to wait until it can be harvested for pulpwood. On the other hand, if the sapling stand is sparsely stocked, the owner may consider converting to pine.

Management Alternatives on Poor and Medium Oak Sites

For stands that have been commercially clear cut and for poorly stocked seedling and sapling stands, the forest manager will have several timber production alternatives. These alternatives are as follows:

1. Wait 40 to 80 years and eventually harvest oak pulpwood and some sawtimber. The yield that can be expected will depend on the present stand stocking. Yields from commercially clear-cut stands will be reduced 25 to 50 percent if no further work is done, because the many cull trees left standing will suppress new sprout growth. This "do nothing" alternative will produce a few dollars worth of timber if annual expenses are not charged to the timber production (table 15).

2. Kill back the tops of all remaining trees that are more than 2 inches in diameter; a fully stocked stand can be expected from this treatment. A spring or fall burn immediately after the clear cut will not only kill back most of the small suppressed trees and promote sprouting, but it will also char the stumps, and retard high stump sprouts that often develop heart rot. A 25-percent increase in stocking will increase pulpwood yield about $1 or less per acre (table 15); therefore treatment costs need to be kept low.

3. Convert to red pine. A better financial return can be obtained by investing $40 to $50 per acre to convert to pine. This will be true even with annual costs up to $1 per acre (table 16). However, this is assuming the investor will be satisfied with a 4-percent return on his long-term investment. If 6-percent interest or higher is desired, conversion at present costs with the expected future yield does not appear profitable. Nearly full stocking of pine is required with periodic thinnings for pulpwood and a harvest cut for sawtimber. The most profitable rotation is 60 years for pine. Managing for pine pulpwood alone would not be profitable with the proposed conversion costs and stumpage prices. In other words, if the forest manager attempts to convert oak on poor and medium sites to pine, he must manage intensively to make a profit on the investment.

Converting Oak on Poor and Medium Sites to Pine

Many stands of mixed oak on poor and medium sites have been successfully converted to pine — mainly red pine — in the northern Lake States. Although converting to pine can, under certain conditions, produce a profitable return on the investment, this alternative may not always be the most profitable or best use of the land. For example, when a limited amount of capital is available for managing a wide range of oak lands, the highest return can be obtained by investing in improvement cutting and thinning in overstocked pole and small sawtimber stands on medium-high and good sites (Herrick and Morse 1968). However, if sufficient capital is left over to manage poor and medium oak sites, converting to pine can be more profitable than growing oak, if the owner is willing to accept 4 percent interest on his investment. In any forest management plan, the potential return from land uses other than timber production must also be considered. If converting to pine will create extensive blocks of conifers that decrease wildlife production and increase fire, insect, and disease protection costs, it may not be the best management alternative. Other potential land uses are discussed in the last section of this publication.

Converting oak to pine is more profitable on medium than on poor sites. Conversion costs will be similar on both sites, but medium sites give nearly twice the return (table 16). Also, a larger oak volume will be harvested on medium sites preparatory to conversion, thus more capital is available for reinvestment.

Table 16. — Present worth of red pine on poor and medium oak sites where the pine is managed for sawtimber with pulpwood thinnings[1]
(In dollars per acre)

Thinning and harvesting schedules	Stocking percent	Conversion costs	Present worth of timber at 4 percent interest when annual costs are: $ 0.00 per acre	$ 0.50 per acre	$ 1.00 per acre
POOR SITES (SI 50)					
Thin at 40 years and clearcut sawtimber at 60 years[2]	100	50	41.35	24.20	7.02
		40	51.47	34.32	17.15
	75	50	16.71	-.44	-17.61
		40	26.84	9.69	-7.49
	50	50	-7.92	-25.07	-42.24
		40	2.20	-14.95	-32.12
Thin at 40 and 60 years and clearcut sawtimber at 80 years[3]	100	50	11.30	-6.52	-24.36
		40	20.87	3.05	-14.79
	75	50	-5.05	-22.87	-40.71
		40	4.52	-13.30	-31.14
	50	50	-21.40	-39.22	-57.06
		40	-11.83	-29.65	-47.49
MEDIUM SITES (SI 60)					
Thin at 40 years and clearcut sawtimber at 60 years[2]	100	50	71.39	54.24	37.07
		40	81.51	64.36	47.19
	75	50	39.25	22.10	4.92
		40	49.37	32.22	15.04
	50	50	7.10	-10.05	-27.22
		40	17.22	.07	-17.10
Thin at 40 and 60 years and clearcut sawtimber at 80 years[3]	100	50	32.64	14.82	-3.03
		40	42.21	24.39	6.55
	75	50	10.95	-6.87	-24.71
		40	20.53	2.71	-15.14
	50	50	-10.73	-28.55	-46.39
		40	-1.16	-18.98	-36.82

1/ Stumpage prices used were $3.50 per cord for pulpwood and $25 per M for sawtimber. These prices were increased annually by 0.5 percent for pulpwood and 1 percent for sawtimber. Annual costs were increased 3 percent annually for expected inflation. Conversion costs assumed were (1) $50 for preplanting release and planting approximately 800 3-0 red pine per acre, plus $5 for release in 8 years, and (2) $40 per acre for planting approximately 800 3-0 red pine per acre, plus $5 per acre for release in 5 years. Red pine pulpwood and sawtimber yields at 40, 60, and 80 years were interpreted from U.S. Dep. Agr. Tech. Bull. 1272 (Buckman 1962) for site indexes 50 and 60, with thinning schedules maintained at 90 square feet of basal area. These natural stand yields appear conservative compared to red pine plantation yields measured on comparable sites in northern Lower Michigan.

2/ Thinning and harvesting schedules assumed at 60 years were: thin 15 and 20 cords at 40 and 60 years, respectively; harvest 11.2 and 13.6 M board feet per acre on SI 50 and 60 sites, respectively.

3/ Thinning and harvesting schedules assumed at 80 years were: thin 15 cords per acre at 40 and 60 years; harvest 13.3 M board feet at 80 years on SI 50 sites. On site index 60 sites, thin 20 cords at 40 and 60 years; harvest 15.9 M board feet at 80 years.

Hand planting has been most widely used for converting oak to pine, especially under reasonably well stocked stands of oak. After logging, slash is generally too abundant for machine planting, and it also hinders hand planting. However, in some understocked stands it is possible to machine plant 400 to 600 pines per acre before the oaks are cut. Direct seeding techniques have not been perfected.

Burning the stand with a hot summer fire after commercial clear cutting is currently being tested in Lower Michigan. This practice increases oak sprouting if the fire is not exceptionally hot, but it reduces slash and makes machine planting possible.

When sprouts and competing vegetation start to suppress the pine, an aerial spray applied in early August (1 pound of 2,4,5-T ester diluted in 2 to 3 gallons of oil-water mixture per acre) will release the pine. This can generally be done for about $6 per acre. Where drift from this type of herbicide application may damage adjacent hardwood timber, a helicopter may be used at slightly higher cost. A second release may be needed. Release should not be delayed too long because red pine that is suppressed for several years will not resume normal height growth for about 3 years following release. On the other hand, releasing too early kills back the competing hardwood competition before the pine can utilize the extra growing space.

Poor and medium site oak lands in the agricultural areas in the southern Lake States are mostly narrow ridges, upper slopes, steep south and west slopes, and shallow soil areas. These sites are not often found in large blocks under one ownership, but usually occur in small, scattered tracts. Converting to pine on small tracts can be accomplished by hand planting, and release by herbicides applied with a portable mist blower. Such conversion adds beauty to the landscape and improves the habitat for wildlife, as well as increases timber production.

Oaks Growing in Mixture With Pines

Very Poor Sites

On very poor sites, the main conifer growing in mixture with oak is jack pine. The oaks are nearly worthless for timber and the jack pine will also be of poor quality. About all the timber management that can be justified is fire protection until the trees can be harvested for pulp (both the oak and pine).

Poor and Medium Sites

The northern pines — jack, white, and red — can all be found growing in mixture with oaks on poor and medium sites. On these sites the pines will produce more and higher quality timber than oak. The pines, especially white pine, will also seed in under the oak.

The oaks should be removed when they start to suppress the pine. This release can be accomplished by logging if the trees are merchantable, or by aerial sprays of 2,4,5-T if they are unmerchantable.

Good Sites

Both red and white pines, but most commonly white pine, may be found growing with oak on good sites. The pines cannot compete with hardwoods on good oak sites. Therefore, it is advisable to harvest the mature pine and manage the stand for high-quality hardwood sawtimber.

Multiple Use for Oak Land

The long-term rate of return from young oak stands will be low in most cases. On poor and medium sites the projected return from oak timber at age 40 or more is not even expected to pay the minimum annual expenses of owning the land, not to mention silvicultural costs to increase timber values (table 15). The highest return can be expected from young, well stocked sawtimber stands growing on good sites. These oak stands should receive the highest priority when investing in silvicultural practices (table 17).

The oaks are ideal multiple-use trees. They provide large quantities of food for deer, squirrels, grouse, turkeys, and many nongame species, and make excellent shade trees. White oak is especially durable and long-lasting. Bur oak is well suited for picnic areas and camping sites because it tolerates dry sites. Of course the oaks, like most trees, succumb where the soil is severely compacted by automobiles and campers, but they withstand this type of use better than most tree species.

On poor and medium oak sites, the highest monetary returns from timber production can be expected by converting to red pine (table 16). However, in the northern Lake States, where large acreages of conifers already exist, the forest manager is often challenged with growing a timber crop that will help pay ownership expenses and at the same time enhance the value of the forest for other outdoor uses. This is especially important on publicly owned lands. Since, in this case, annual expenses need not be met by timber sales alone, managing for oak may well return a greater benefit in the long run than conversion to pine.

Converting to pine may yield the greatest total return in the agricultural lands of the southern part of the region. Here, poor and medium oak sites are intermingled with good and highly productive sites, and land values are high. Because most of the forests in this area are hardwood, scattered pine stands would increase timber yields, beautify the landscape, provide additional wildlife habitat, and increase outdoor recreation potential.

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Table 17. — Summary of silvicultural prescriptions and investment priorities

MEDIUM-HIGH TO VERY GOOD SITES (SI 65 TO 80)

Stand size and stocking[1/]	Silvicultural prescription	Investment priority
Small sawtimber		
Fully stocked	TSI and thin	Very high
Understocked	TSI and prune	Low
Poles		
Fully stocked	TSI and thin	High
Understocked	None or limited TSI	Low
Seedlings and saplings		
Fully stocked	Cleaning	Low
Understocked	None, burn or plant	Very low
MEDIUM-LOW TO POOR SITES (SI 40 TO 60)		
Small sawtimber and poles		
All stockings	None	--
Saplings		
Fully stocked	None	--
Understocked	None or convert to pine	Low
Seedlings		
All stocking	None or convert to pine	Low

1/ See range of full stocking in table 13. Understocked would be less than the minimum values listed for full stocking.

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COMMON AND SCIENTIFIC NAMES OF TREES, SHRUBS, AND PLANTS MENTIONED

Ash, white	*Fraxinus americana* L.
Aspen, bigtooth	*Populus grandidentata* Michx.
Aspen, quaking	*Populus tremuloides* Michx.
Basswood, American	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, paper	*Betula papyrifera* Marsh.
Blackberry	*Rubus* spp.
Boxelder	*Acer negundo* L.
Butternut	*Juglans cinerea* L.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pensylvanica* L. f.
Chokecherry, common	*Prunus virginiana* L.
Cottonwood, eastern	*Populus deltoides* Bartr.
Dogwood, flowering	*Cornus florida* L.
Dogwood, gray	*Cornus racemosa* Lam.
Elm, American	*Ulmus americana* L.
Elm, rock	*Ulmus thomasii* Sarg.
Elm, slippery	*Ulmus rubra* Muhl.
Gooseberry	*Ribes* spp.
Hawthorn	*Crataegus* spp.
Hazel, American	*Corylus americana* Walt.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr
Hickory, bitternut	*Carya cordiformis* (Wangenh.) K. Koch
Hickory, pignut	*Carya glabra* (Mill.) Sweet
Hickory, shagbark	*Carya ovata* (Mill.) K. Koch
Hophornbeam, eastern	*Ostrya virginiana* (Mill.) K. Koch
Hornbeam, American	*Carpinus caroliniana* Walt.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, black	*Quercus velutina* Lam.
Oak, blackjack	*Quercus marilandica* Muenchh.
Oak, bur	*Quercus macrocarpa* Michx.
Oak, chestnut	*Quercus prinus* L.
Oak, chinkapin	*Quercus muehlenbergii* Engelm.
Oak, northern pin	*Quercus ellipsoidalis* E. J. Hill
Oak, northern red	*Quercus rubra* L.
Oak, pin	*Quercus palustris* Muenchh.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, shingle	*Quercus imbricaria* Michx.
Oak, swamp white	*Quercus bicolor* Willd.
Oak, white	*Quercus alba* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, red	*Pinus resinosa* Ait.
Pine, white	*Pinus strobus* L.
Raspberry	*Rubus* spp.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Serviceberry	*Amelanchier* spp.
Walnut, black	*Juglans nigra* L.
Yellow-poplar	*Liriodendron tulipifera* L.

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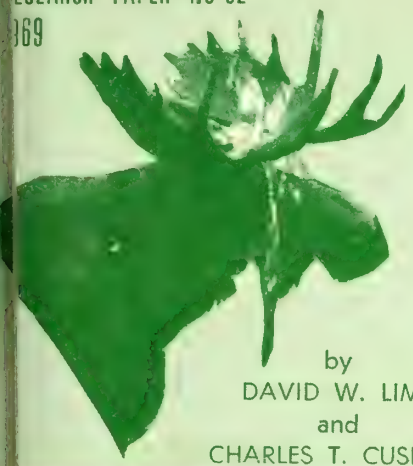

wildlife esthetics & auto campers

IN THE SUPERIOR NATIONAL FOREST

by
DAVID W. LIME
and
CHARLES T. CUSHWA

FEB 5 1970
S.L. TECH. & ACR. DIV.

RTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

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WILDLIFE ESTHETICS AND AUTO CAMPERS IN THE SUPERIOR NATIONAL FOREST[1]

David W. Lime and Charles T. Cushwa

Many people involved in recreation research agree that the presence of wildlife adds substantially to the esthetic attraction of a forest setting. Yet, little is actually known about the importance of wildlife from the forest visitor's standpoint. It is simply assumed that he wants to see wildlife — but what kinds he would like to see, what kinds he does see, and how much his contact with wildlife adds to the enjoyment of his trip is unknown. These questions are not easily answered, because esthetic values are difficult to describe and even more difficult to evaluate in meaningful terms. Many resource managers and researchers have recognized this problem (Drury 1947, Sears 1951, Christy 1967); but, for the most part, research efforts have failed to meet the issue face to face.

Most of the previous research that has attempted to place a "value" on wildlife has done so by determining its dollar value — largely from hunting and fishing. For example, between 1952 and 1960, 44 such studies were reviewed in *Wildlife Abstracts*. These, plus more recent studies, have provided new insights into the importance of wildlife in the American economy and have answered many questions that confront resource administrators. Nevertheless, while economic studies have been numerous, a search of the literature produced not one research effort in which the nonconsumptive or esthetic value of wildlife was pursued in depth. Yet, in many papers it was tacitly assumed that contact with wildlife is rewarding for nearly *all* people, and that it is a primary reason for many outdoor excursions.

While many researchers and resource managers place wildlife high on the "plus" list of features of the natural environment, there are few facts available to support or contradict this judgment. Seeing birds and mammals is certainly rewarding to many Americans; for example, there are over 8 million bona fide birdwatchers in our country. Nonetheless, research to date has not provided a scientific evaluation of the esthetic importance of wildlife. In short, we think wildlife is important, but we don't know how important or to whom.

To gain some insight into the esthetic importance of wildlife to the forest visitor, we conducted a canvass of auto campers in the Superior National Forest in northeast Minnesota. Our study did not attempt to measure the importance of wildlife in any economic sense, but sought to find out why people came to the National Forest, where they came from, how many observed wildlife, what kinds of wildlife they observed, and whether seeing wildlife added to or detracted from their experience, and why.

[1] *The findings presented in this report also were presented by the senior author at the Northeast Fish and Wildlife Conference held at White Sulphur Springs, West Virginia, February 9-12, 1969, and appear in the 1969 Transactions.*

THE STUDY AREA AND METHODS

The area of northeast Minnesota that includes the Superior National Forest is characterized for the most part by a low concentration of people and limited commercial development. The primary attraction of the area is its extensive water resource in a wild land forest setting. Another major attraction is the Boundary Waters Canoe Area (BWCA). This is the Nation's only water-oriented Wilderness Area, and it occupies about 1 million of the Forest's 3 million acres. Most auto campers questioned in this study did not enter the BWCA, but many were well aware of its presence and recreational appeal.

Thirty-one auto campgrounds distributed throughout the Forest were included in the study. These campgrounds were characterized by a low level of modern development and general remoteness from the major travel routes of the area. Twelve campgrounds had no source of drinking water except lake or stream, only one had flush toilets, and only three were located adjacent to a paved road.

The importance of wildlife to forest visitors is probably related to the opportunities to see or hear wildlife in the area. Bird and mammal check lists for Minnesota show 292 different species of birds and 80 species of mammals present in the State (Buckmann 1968, Anon. 1968), many of which inhabit northeast Minnesota (fig. 1). Also, the Superior National Forest provides an opportunity to see or hear moose (*Alces alces*), timber wolves (*Canis lupus*), and common loons (*Gavia immer*); these wildlife species are more common here than in other parts of the Midwest, South, and East. Thus, ample opportunities exist in the study area to see and enjoy wildlife in its natural environment if the visitor so desires.

During the peak of the 1968 camping season (the latter part of July and August), 248 auto campers were interviewed.

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FIGURE 1. — Visitors in auto campgrounds adjacent to lakes and streams may see a bald eagle, the national bird, looking for a fish dinner near the water or perched in his nest of sticks high in a pine tree.

RESULTS

Who Were the Visitors?

Sixty-six percent of the auto campers came from Minnesota, and 15 percent from Illinois; 85 percent of all campers were on extended vacations. The average length of stay for vacationers was 7.2 days. This suggests that in terms of time spent in the forest environment, most people had ample opportunity to be exposed to the wildlife of the area. Most campers also had some previous experience in northeast Minnesota. Eighty-nine percent of the parties had been in the area before, and 65 percent had previously camped in the Superior National Forest.

Why Did Visitors Select Northeast Minnesota?

Campers were asked, "Why did you select northeast Minnesota and the Superior National Forest in particular for your camping trip?" The question was left unstructured in an effort to explore the range of choices. Campers were encouraged to state freely those factors that immediately came to mind. Thus, the array of responses given represented a crude index of the features that made the area most attractive to its visitors.

Replies included 49 different reasons for visiting the area, and specific reasons were not mutually exclusive. An average of three reasons was given per party.

Fishing appeared to be the major attraction of the area, with wilderness second (table 1). However, it is apparent that numerous aspects of the natural environment combine to form a specific sought-for atmosphere. While many people mentioned specific activities as the reason for choosing the area, they apparently desired to do these things in a specific kind of environmental setting. This suggestion is substantiated by the fact that 63 percent of those noting fishing as an attraction also mentioned at least one of the following three things as important in pulling them to northeast Minnesota: (1) wilderness, (2) quiet, peaceful, uncrowded, or (3) scenery. The attraction of this area, then, is not a single factor but a combination of factors. Recent studies have found this to be true in other parts of the United States and Canada (Gordon Lusty Survey Research Ltd. 1968, Hendee 1967, Taylor and Edwards 1960).

Table 1. — Responses to "Why did you select northeast Minnesota and the Superior National Forest, in particular, for your (1968) camping trip?"

Reasons	Respondents1/ (Total - 248)	
	Number	Percent
Fishing	154	62
Wilderness	103	42
Quiet, peaceful, uncrowded area	54	22
Scenery	53	21
Water-based activities (excluding fishing)	37	15
Getting away from city, routine, etc.	37	15
Camping in a National Forest	35	14
Lake Superior	27	11
Relatively close to home	25	10
Land-based activities (berry picking, hiking, driving, rock hounding)	24	10
Presence of many lakes and streams	24	10
New part of U.S.A. to visit	23	9
Visit friends in area	23	9
WILDLIFE	19	8
Other aspects of natural environment:		
Weather	19	8
Vegetation	12	5
Topography	6	2
Other activities:		
Visiting BWCA	17	7
Visiting Canada	10	4
Visiting iron mines	2	1
All other	4	2

1/ Many respondents gave more than one reason.

Perhaps surprising to many is the fact that wildlife apparently was not a prime factor in bringing auto campers to the area. Only 8 percent (19 parties) cited this aspect of the forest environment as an attraction. Thirteen of these 19 parties stated that wildlife in general prompted their visit. Others specifically listed bears (*Ursus americanus*) (2 parties), loons (2), wolves (1), and moose (1) as species they hoped to see (figs. 2, 3).

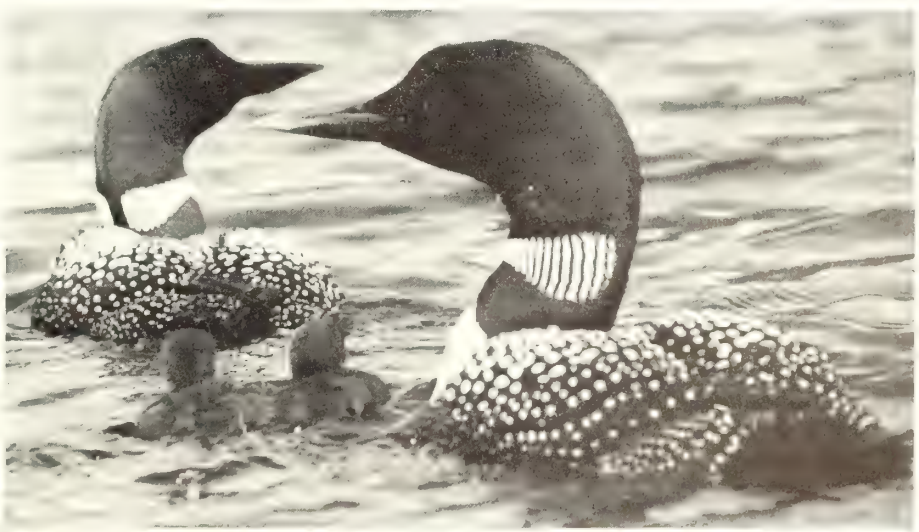

FIGURE 2. — Minnesota's state bird, the loon, is a common summer resident in lakes of northern Minnesota. Its piercing, yodel-like cry is a sound of the north country to which many parents like to call their children's attention. (Photo courtesy of the *Naturalist*)

F-314077
FIGURE 3. — The largest of all Minnesota mammals, the moose, is at home in the conifer and muskeg country of northern Minnesota.

Parties that mentioned wildlife as a reason for visiting northeast Minnesota also were motivated by the atmosphere of the area (table 2). Fifteen of the 19 parties (79 percent) that listed wildlife also noted one of the following three categories: (1) wilderness, (2) quiet, peaceful, uncrowded, or (3) scenery. Again, it is apparent that the lure of the area cannot be attributed to any one factor — wildlife represents only one of the many forest resources that make up this general atmosphere.

What Esthetic Effect Did Wildlife Have on the Visitor?

As a supplementary benefit to campers, the wildlife resource can hardly be challenged. Ninety percent (223 parties) of those questioned had seen wildlife of some type. Of these, 96 percent (215) said that the opportunity to observe birds and mammals in their natural setting had added to their outdoor experience (fig. 4). Only two parties felt that wildlife had detracted from their visit, and this was due to unpleasant contact with bears in the campground during the night. The remaining six parties that had seen wildlife felt that seeing these creatures had neither added to nor detracted from their visit.

Table 2. — Responses to "Why did you select northeast Minnesota and the Superior National Forest, in particular, for your (1968) camping trip?"

Reasons	Respondents who noted wildlife as an attraction1/ (Total - 19)	
	Number	Percent
Fishing	10	53
Wilderness	7	37
Quiet, peaceful, uncrowded area	7	37
Scenery	5	26
Water-based activities (excluding fishing)	3	16
Getting away from city, routine, etc.	2	11
Camping in a National Forest	1	5
Lake Superior	1	5
Presence of many lakes and streams	2	11
Relatively close to home	1	5
Land-based activities (berry picking, hiking, driving, rock hounding)	2	11
New part of U.S.A. to visit	2	11
Visit friends in area	0	0
Other aspects of natural environment:		
Vegetation	4	21
Topography	1	5
Weather	0	0
Other activities:		
Visiting BWCA	1	5
Visiting Canada	1	5
Visiting iron mines	0	0
All other	1	5

1/ Many respondents gave more than one reason.

F-519379

FIGURE 4. — Self-guiding nature trails are becoming increasingly popular with visitors who desire to learn more about the forest environment.

What tangible benefits were afforded those 215 parties who felt that seeing wildlife added to their outing? Many parties (90) had difficulty in stating a definite benefit, but said that they "just enjoy watching them," for instance; others however, were explicit (table 3). Responses such as "adds to the feeling of wilderness," and "being close to nature," indicate that wildlife did have a pronounced effect on the forest experience of a number of campers. It also suggests that wildlife is, in part, associated with people's perception of that hard-to-define word *wilderness*.

Table 3. — Responses to "Why did seeing wildlife ADD to your (1968) camping trip in the Superior National Forest?"

Reasons	Respondents	
	Number	Percent
Just enjoy watching them	90	42
Educational for the youngsters	47	22
Adds to the "feeling of wilderness" or "being close to nature"	45	21
Enjoy watching them and don't see them often in their natural setting	17	8
Adds excitement, especially bears in the campgrounds	11	5
All other	5	2
Total	215	100

Particularly interesting and encouraging is the implication for the education of children (table 3). This parental concern and awareness should strengthen the plea to update public education by establishing conservation as an integral part of the school curriculum. Moreover, numerous persons, adults and children alike, expressed ignorance of the creatures around them, birds especially, and voiced a desire to learn more about this aspect of the forest environment.

This lack of awareness of wildlife is exemplified by the fact that surprisingly few species of birds and mammals were actually seen by campers. The number of different mammals seen per party ranged from 0 to 8 and averaged 3. Chipmunks (*Tamias striatus*), red squirrels (*Tamiasciurus hudsonicus*), black bears, and white-tailed deer (*Odocoileus virginianus*) were the most frequently observed species (fig. 5). The number of different birds seen per party ranged from 0 to 12 and averaged 2. It is noteworthy that few species of songbirds were actually identified. Many campers simply referred to them as "'just little birds." Part of this apparent "ignorance" might be attributed to the fact that few of the campers were bona fide wildlife observers — that is, none belonged to a birdwatching organization and only 10 parties (4 percent) actually considered themselves birdwatchers per se.

F-519380

FIGURE 5. — A friendly red squirrel is a frequent unexpected dinner guest.

DISCUSSION

The results of the study suggest that a higher level of education regarding wildlife would substantially increase the esthetic importance of the wildlife resource to the recreationist. Growth of conservation in the public school curriculum is only one avenue for increasing public contact with wildlife. Land managers could provide brochures characterizing the wildlife species of their specific locale. Such brochures could list the distinguishing characteristics of various species, describe the habitat in which they are most likely to be found, indicate the best time of day for successful observation, provide safety tips for observing or avoiding potentially dangerous species (fig. 6), and describe the techniques being used to preserve and sustain the wildlife resource.

Some individuals may wonder if organized interpretative programs are indeed the responsibility of the land manager. We believe that they are. An informed citizenry should be better able to understand the challenges facing land managers in their attempt to provide for the diverse and fast-growing desires of the recreating public. Also, an informed public should be more willing to cooperate in protecting the resource itself, and to take an active part in conservation activities.

FIGURE 6. — Bears are often seen around auto campgrounds in the Superior National Forest. While not naturally aggressive, bears can be dangerous when looking for food or protecting their young, and should be avoided at all times. (Photo courtesy of the *Naturalist*)

The results of this study indicate a need for continued research into other aspects of the wildlife resource as it relates to the total experience of visitors. If land managers are to make sound decisions as to how much, what types, and where outdoor recreation is to be provided, many pertinent questions will have to be answered. For instance, what proportion of forest visitors are attracted specifically by the esthetic values associated with observing wildlife? What segments of the population do these people represent? How aware are they of the different wildlife species around them? Which species enhance their visit most? Do their attitudes regarding the importance of wildlife to their outdoor experience change over time? What techniques or aids can resource managers provide the public that will further enhance visits to the out-of-doors?

SUMMARY

The results are preliminary and represent but one isolated example of the behavior of the recreating public. Although wildlife was of esthetic benefit to many of the auto campers in the survey, it was not a prime motivational factor in attracting them to the forest environment of northeast Minnesota. Most visitors were seeking a remote or wilderness-like area for summer recreation that afforded a maximum contrast to their urbanized living. They were attracted by the natural atmosphere of the area in general, and wildlife represented only one small component of that general atmosphere.

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SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

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Paper Birch, Its Characteristics, Properties, and Uses, A Review of Recent Literature, by Matti J. Hyvarinen. U.S.D.A. Res. Pap. NC-22, 12 p., illus. 1968.

Proceedings of the Eighth Lake States Forest Tree Improvement Conference, September 12-13, 1967, by North Central Forest Experiment Station. U.S.D.A. Forest Serv. Res. Pap. NC-23, 60 p., illus. 1968.

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STANDING TIMBER COEFFICIENTS FOR INDIANA WALNUT LOG PRODUCTION

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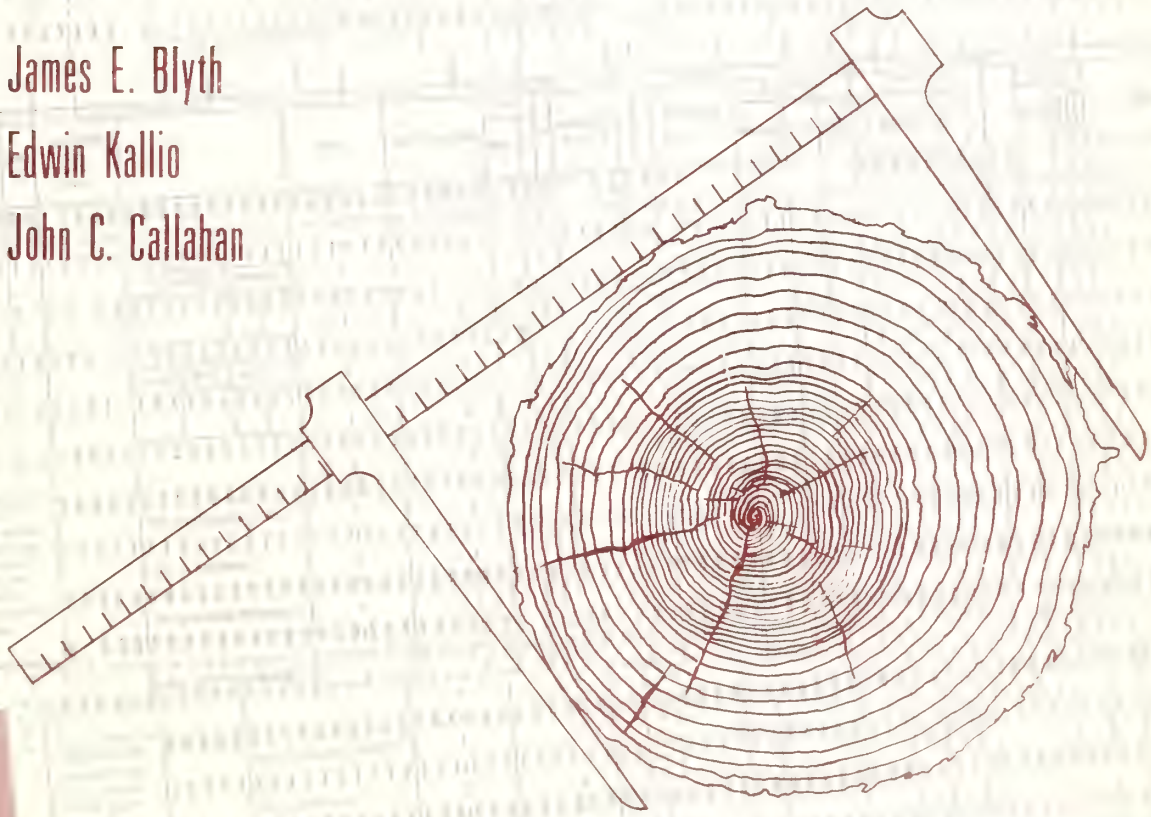

NORTH CENTRAL FOREST EXPERIMENT STATION
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Standing Timber Coefficients for Indiana Walnut Log Production

James E. Blyth, Edwin Kallio, and John C. Callahan

The problem of effectively utilizing walnut timber has been magnified in recent years because of the rapidly increasing demand for this valuable species. Reliable converting factors related to current logging practices are needed to provide more accurate estimates of the volume of walnut timber cut. These statistics are needed to provide a better appraisal of the walnut resource, especially in comparing the timber cut with growth. Up-to-date information on the kinds and amounts of logging residue may provide the basis for better utilization, which would extend the available walnut resource. Information about the amount of walnut harvested from nongrowing-stock sources will also improve estimates of the total drain.

During 1966 a study was made by the U.S.D.A. Forest Service in cooperation with Purdue University to develop factors for converting the volume of rough walnut saw logs and veneer logs cut in Indiana to the volume of standing timber that was actually cut to produce these logs. In addition, the study revealed the size of walnut trees cut for products, their quality, and the volume coming from nongrowing-stock sources. Prior to this study, reliable converting factors for walnut timber cut in Indiana were not available. Those most commonly used in the past were developed mainly for broad species groups. Because less growing stock is usually cut per thousand board feet of logs produced for a high-value species like walnut, utilization factors for lower-value species will usually overestimate the walnut timber cut from growing stock.

With two exceptions, technical terms used throughout this paper are those used in Forest Survey and are defined in the Appendix. The exceptions are "growing stock" and "nongrowing stock." Growing stock, by Forest Survey definition, includes sawtimber and poletimber trees on nonforest land. In this paper such trees on nonforest land are classified as nongrowing stock. In most Forest Survey publications only the growing stock on commercial forest land is discussed.

Thus, growing-stock volume includes the saw-log portion (merchantable stem) and upper-stem portion of sawtimber trees on commercial forest land. Nongrowing-stock volume includes limbwood, cull trees and logs, and trees on nonforest land.

PROCEDURES

One hundred and forty walnut[1] trees were measured after felling and bucking at 19 logging operations in 1966. About half the trees were located in northeast and half in west central Indiana (fig. 1).

[1] *The volume of the 140 sample trees was 0.137 percent of the total walnut growing stock volume cut for products in Indiana in 1966. Past Forest Service studies in the North Central States have been considered adequate for calculating conversion factors if 0.01 percent of the volume cut was measured.*

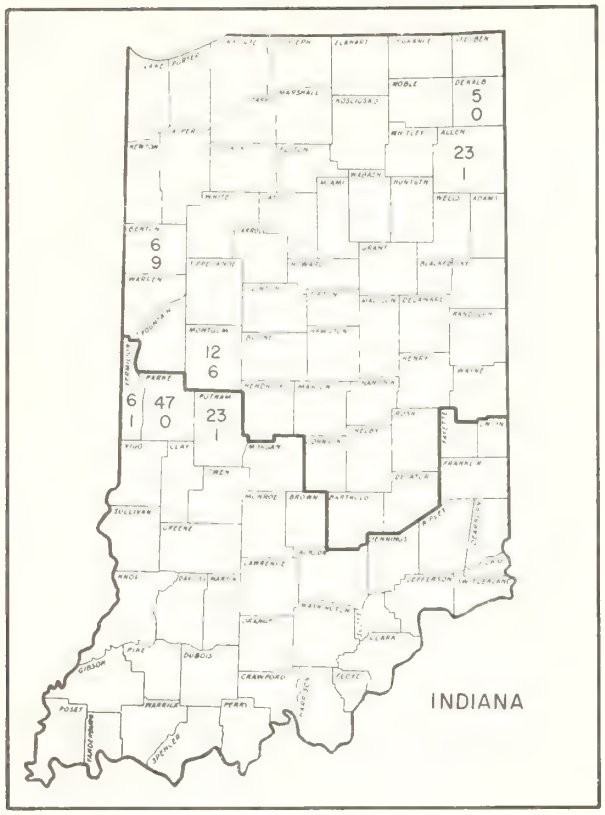

FIGURE 1. — Number of walnut trees measured by county. Top figure in each county indicates growing-stock trees, bottom figure nongrowing-stock trees.

Selection of Logging Operations and Sample Trees

Logging operations were found by talking to sawmill and veneer mill operators using walnut logs. Wherever possible, both single-product oriented and integrated logging operations were selected. No more than 10 walnut trees cut for veneer nor more than 10 trees cut for saw logs were measured at any single operation. Because few walnut trees were present on each logging operation, usually all of them were included in the sample.

Individual Tree Measurement

Each tree was classified as live-merchantable, cull, or dead. Tree origin was classed as commercial forest or nonforest land. The saw-log length and growing-stock length were measured. Then each log or bolt cut for a product was measured. Length was recorded to the nearest 1/10 foot and the top diameter inside bark to the nearest 1/10 inch. Each log was classified according to its use — veneer log or saw log. The gross and net board foot and cubic foot volumes (after cull deduction) were determined for each log, using table 4 (Appendix). As each log or bolt was measured, it was assigned to the proper tree class (live, dead, or cull). If logs or bolts were from dead or cull trees, their volumes were recorded as such. Logs or bolts from live trees, however, were next assigned to the proper land class (commercial forest land or nonforest land). Volumes of logs or bolts from nonforest land trees were recorded as such. If logs or bolts were from commercial forest land trees, however, their volumes were assigned to the proper tree-portion class (saw-log portion, upper stem, or limbwood). Every log was graded according to the system published in Report No. D1737-A of the Forest Products Laboratory, U.S.D.A. Forest Service.

Any growing stock that was cut and left in the woods as unmerchantable was considered logging residue. Each section of logging residue was measured and recorded for board foot and cubic foot volume (fig. 2).

FIGURE 2. — Unmerchantable growing stock was measured and the volume recorded as logging residue. (Photo courtesy of Dr. John C. Callahan, Purdue University)

Damage inflicted by the sample tree to surrounding trees during felling, bucking, and skidding was taken into account; volume of damaged trees was measured if they would die from their injury and remain unused. The net volume of damaged timber was recorded separately for cull trees, saplings, poletimber trees, and sawtimber trees.

RESULTS

Of the 140 walnut trees measured immediately after felling and bucking into products, 122 were growing-stock trees and 18 nongrowing-stock trees. All the trees cut were sawtimber-size (table 1); the smallest tree was 11.8 inches diameter at breast height (d.b.h.), and two-thirds of the growing-stock trees were 13.0 to 17.9 inches d.b.h. The nongrowing stock trees were larger on the average and included 2 culls and 16 trees from nonforest land.

Table 1. — Number of sample growing-stock and nongrowing-stock trees by diameter class

Diameter class (d.b.h. in inches)	Number of trees	
	Growing stock	Nongrowing stock
11.0-11.9	1	-
12.0-12.9	9	1
13.0-13.9	18	-
14.0-14.9	30	2
15.0-15.9	20	1
16.0-16.9	15	1
17.0-17.9	9	3
18.0-18.9	3	1
19.0-19.9	10	2
20.0-20.9	3	2
21.0-21.9	2	3
22.0-22.9	-	1
23.0-23.9	1	-
24.0-24.9	-	-
25.0-25.9	-	1
26.0-26.9	1	-
Total	122	18

Eighty-four percent of the volume in this sample of 140 harvested trees was growing stock. The standard error for growing stock was 3.5 percent. Uses of the trees by product classes were as follows:

Products cut from tree	Number of trees	
	Growing stock	Nongrowing stock
Saw logs only	61	13
Saw logs major,[1] veneer logs minor	35	2
Veneer logs only	1	1
Veneer logs major, saw logs minor	25	2
Total	122	18

[1] *A major product must contain more than 50 percent of the tree volume used for products; a minor product contains less.*

From the 140 sample trees, 279 saw logs and 84 veneer logs were cut. Most of the saw logs were 10 to 14 inches in small-end diameter inside bark (d.i.b.) and 8 to 13 feet long. Veneer logs were primarily 12 to 16 inches d.i.b., small end, and 6 to 14 feet long. According to this sample, few walnut veneer logs under 12 inches d.i.b. are used in Indiana, whereas saw logs are taken to a minimum of 7 inches d.i.b. The average veneer log and saw log contained 89 and 57 net board feet,[2] respectively.

Slightly over half of the saw-log volume came from Grade 3 logs, and about one-fourth from Grade 2 logs (fig. 3). As expected, nearly all the Grade 1 logs went to veneer mills. Two-thirds of all veneer-log volume came from Grade 1 and 2 logs. Logs below Grade 3 constituted 17 percent of the total log volume used for products.

Over 23,000 board feet of logs were produced from the sample trees; slightly more than two-thirds of this volume was saw logs and the rest was veneer logs (table 2). Of the 15,979 board feet of saw logs cut, 83.0 percent came from growing-stock volume on commercial forest land, 12.7 percent came from trees on nonforest land, and the remainder came from cull trees, cull logs, and

[2] *International ¼-inch log rule.*

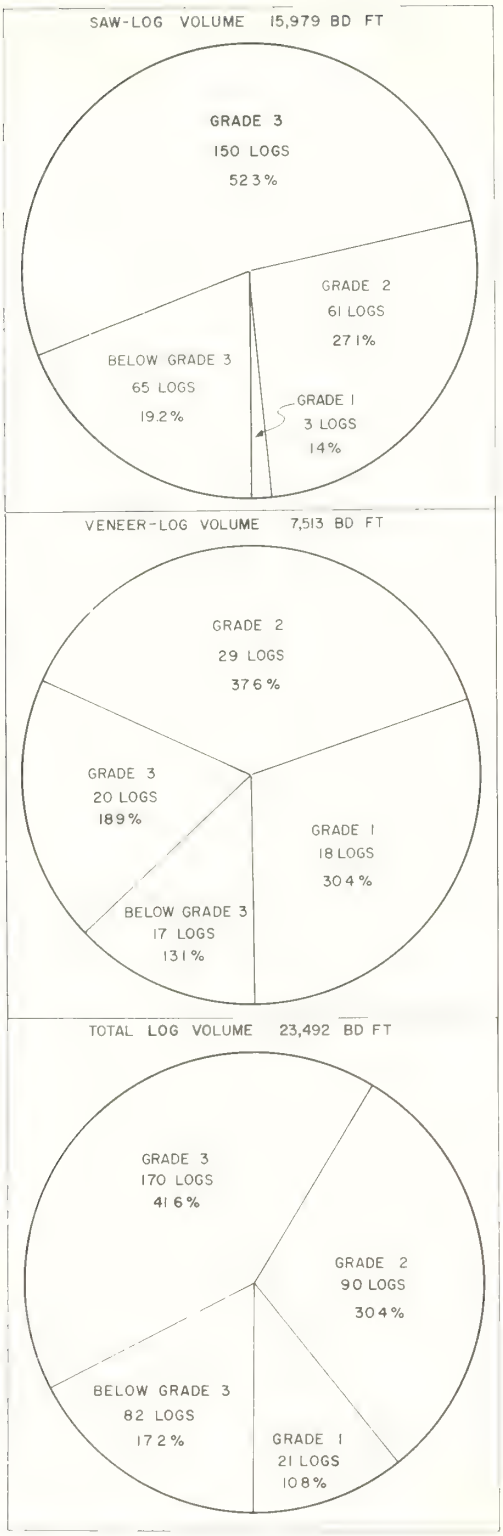

FIGURE 3. — Number of walnut saw logs and veneer logs and percent of volume by log grade, 140 sample trees, Indiana, 1966. Board-foot volumes are International ¼-inch log rule.

limbwood. As for the 7,513 board feet of veneer logs produced, 87.2 percent was growing-stock volume on commercial forest land — the remainder was from trees on nonforest land.

As shown in table 2, nearly one-sixth of the total saw-log and veneer-log volume came from nongrowing-stock sources — limbwood, cull trees and logs, and trees on nonforest land. Most of this nongrowing-stock log volume was cut from trees on nonforest land, a reflection of the high value of walnut products and the economic feasibility of removing one or a few walnut trees from a nonforest logging area. Because nonforest land is an important source of walnut logs in Indiana, resource analysts should include it when making growth and cut comparisons.

Logs cut from all sample trees contained 3,506 cubic feet, of which 2,965 cubic feet came from growing-stock trees. In spite of the high value of walnut products, 15 percent of the growing-stock volume was left in the woods as logging residue. About two-thirds of this residue came from the saw-log portion of the tree, and the remainder from the upper stem portion of sawtimber trees. Walnut logging should be carefully scrutinized for opportunities to utilize this significant amount of residue. The chance is only 1 in 20 that the actual percent of growing stock used for products is lower than 79 or higher than 92.

Based on the sample trees, 181.8 cubic feet of timber must be felled to provide 1,000 board feet of saw logs at a sawmill (table 3). This total consists of 153.1 cubic feet of saw logs and 28.7 cubic feet of logging residue. The saw-log volume comes from both growing stock (sawtimber) and nongrowing stock (cull trees and logs, limbwood, and trees on nonforest land) (fig. 4). On the average, each 1,000 board feet of saw logs contains 127.8 cubic feet of growing stock and 25.3 cubic feet of nongrowing stock. All the saw logs from growing stock come from the saw-log portion of sawtimber trees. The 25.3 cubic feet of nongrowing stock in each 1,000 board feet of saw logs contains 2.8 cubic feet of limbwood, 4.1 cubic feet from cull trees and logs, and 18.4 cubic feet from trees on nonforest land.

Table 2. — Volume of saw logs, veneer logs, and logging residue by source from 140 walnut trees, Indiana, 1966

BOARD FEET[1/]

Product	Growing stock [2/]		Non-growing stock [3/]				
	Sawtimber		Limb-wood	Sap-lings	Cull trees	Non-forest land	Total
	Saw-log portion	Upper stem					
Saw logs	13,261	-	306	-	379	2,033	15,979
Veneer logs	6,548	-	-	-	-	965	7,513
Total	19,809	-	306	-	379	2,998	23,492
CUBIC FEET							
Saw logs	2,041.7	-	45.7	-	66.1	293.6	2,447.1
Veneer logs	923.5	-	-	-	-	135.4	1,058.9
Total	2,965.2	-	45.7	-	66.1	429.0	3,506.0
CUBIC FEET							
Saw-log residue	264.0	125.4	-	9.9	58.5	-	457.8
Veneer-log residue	87.1	28.6	-	3.6	65.8	-	185.1
Total	351.1	154.0	-	13.5	124.3	-	642.9

1/ International 1/4-inch log rule.
2/ No products were cut from poletimber-size trees.
3/ No products were cut from dead trees.

Similarly, the logging residue resulting from harvesting saw logs comes from both growing stock and nongrowing stock. According to the sample, each 1,000 board feet of saw logs cut results in 24.4 cubic feet of logging residue from growing stock and 4.3 cubic feet from nongrowing stock. The 24.4 cubic feet of growing stock residue is from sawtimber trees — 16.5 cubic feet from the saw-log portion, and 7.9 cubic feet from the upper stem. The 4.3 cubic feet of nongrowing stock residue consists of 3.7 cubic feet of cull, and 0.6 cubic feet of saplings.

Overall, walnut veneer logs come from larger-diameter trees than saw logs. Because the larger trees have higher board-foot to cubic-foot ratios, only 165.6 cubic feet of walnut is cut to provide 1,000 board feet of veneer logs at the mill. In other words, the cubic-foot volume of walnut timber harvested to produce 1,000 board feet of veneer logs is, on the average, 9 percent less than the cubic-foot volume harvested to produce 1,000 board feet of saw logs. Of the 165.6 cubic feet of walnut timber required to provide 1,000 board feet of veneer logs, 24.7 cubic feet is logging residue.

Table 3. — Volume of Indiana walnut timber cut to provide 1,000 board feet[1] of saw logs or veneer logs at a primary wood-using plant, 1966

Source of timber cut	Saw logs		Veneer logs	
	Bd. ft.	Cu. ft.	Bd. ft.	Cu. ft.
Timber products output:				
From growing stock:				
Sawtimber trees:				
Saw log portion	830	127.8	872	122.9
Upper stem	0	0	0	0
Poletimber trees	0	0	0	0
Subtotal A	830	127.8	872	122.9
From nongrowing stock:				
Limbwood	19	2.8	0	0
Saplings	0	0	0	0
Cull trees and logs	24	4.1	0	0
Dead trees	0	0	0	0
Nonforest land	127	18.4	128	18.0
Subtotal B	170	25.3	128	18.0
Total timber products output (net volume of product received at processing plant)	1,000	153.1	1,000	140.9
Logging residue:				
From growing stock:				
Sawtimber trees:				
Saw log portion	94	16.5	64	11.6
Upper stem	--	7.9	--	3.8
Poletimber trees	0	0	0	0
Subtotal C	94	24.4	64	15.4
From nongrowing stock:				
Cull sections	--	3.7	--	8.8
Saplings	0	.6	0	.5
Subtotal D	--	4.3	--	9.3
Total logging residue	94	28.7	64	24.7
Total timber cut:				
From growing stock (Subtotals A + C)	924	152.2	936	138.3
From nongrowing stock (Subtotals B + D)	170	29.6	128	27.3
Total timber cut	1,094	181.8	1,064	165.6

1/ International 1/4-inch log rule

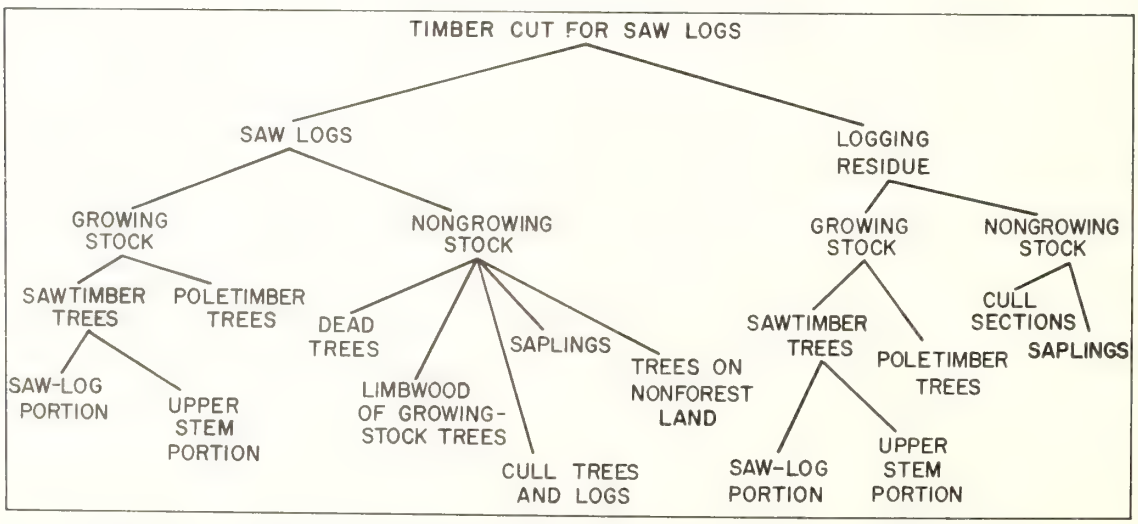

FIGURE 4. — Flow chart showing potential sources of saw logs and logging residue.

DISCUSSION AND CONCLUSIONS

The conversion factors — the principal result of this study — were used to determine the 1966 Indiana walnut timber harvest in the recent Indiana Forest Survey. If the volume[3] of walnut veneer logs and saw logs received at processing plants from Indiana forests is known, the factors in table 3 can be used to determine the amount and kinds of timber that were cut to provide these logs.

The conversion factors are easy to apply. For example, assume that 9 million board feet of saw logs and 6 million board feet of veneer logs were cut in Indiana in 1968. Then, using the appropriate factors in table 3, the following information can be obtained:

Total walnut cut from growing stock:

9,000 (924) + 6,000 (936) = 13,932,000 board feet

9,000 (152.2) + 6,000 (138.3) = 2,199,600 cubic feet

Total logging residue from growing stock:

9,000 (94) + 6,000 (64) = 1,230,000 board feet

9,000 (24.4) + 6,000 (15.4) = 312,000 cubic feet

Total walnut saw log volume from nonforest land:

9,000 (127) = 1,143,000 board feet

9,000 (18.4) = 165,600 cubic feet

Total volume of walnut cut from all sources:

9,000 (1,094) + 6,000 (1,064) = 16,230,000 board feet

9,000 (181.8) + 6,000 (165.6) = 2,629,800 cubic feet

Resource analysts, market analysts and industrial development groups may use these factors in estimating the present volume of Indiana walnut timber cut for saw logs and veneer logs, or in making short-range projections of the future Indiana walnut timber harvest. If net growth of walnut is also known or predicted, then growth and cut can be compared to determine whether the walnut resource is increasing or declining. Such comparisons are important in predicting the future of industries dependent upon walnut, in estimating future costs of walnut logs and stumpage, and in determining walnut log export policies.

[3] *International ¼-inch log rule.*

APPENDIX

Definitions

Commercial forest land. — Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Includes areas suitable for management to grow crops of industrial wood generally capable of producing in excess of 20 cubic feet per acre of annual growth.

Cull trees. — Live trees that do not contain at least one merchantable 12-foot saw log, now or prospectively, because of roughness, poor form, or rot.

Growing stock. — Sawtimber and poletimber trees on commercial forest land.

Growing-stock length. — Length to the last whole foot of the central stem of sawtimber and poletimber trees from ground level to a 4.0-inch diameter outside bark, or to a point where the central stem is terminated by branches, rot, or becomes unmerchantable before reaching the minimum diameter (4.0 inches).

Growing-stock volume. — Volume of sound wood in the bole of sawtimber and poletimber trees from stump to a minimum 4.0 inch top diameter outside bark, or to the point where the central stem breaks into limbs.

Limbwood. — That part of a poletimber or sawtimber tree that does not meet the requirements for growing stock portions of the tree, including all live, sound branches used for products.

Logging residue. — The unused portions of growing-stock trees cut for products.

Nonforest land. — Land that has never supported forests, and lands formerly forested where forest use is now precluded by development for nonforest uses, such as cropland, improved pasture, residential areas, and city parks. Also includes improved roads and adjoining rights-of-way, powerline clearings, and certain areas of water classified by the Bureau of Census as land. Unimproved roads, streams, canals, and nonforest strips in forest areas must be more than 120 feet wide, and clearings in forest areas must be more than 1 acre in size to qualify as nonforest land.

Nongrowing stock. — Cull trees, dead trees, cull sections of live growing-stock trees, limbs, and timber on nonforest land.

Poletimber trees. — Live trees of commercial species on commercial forest land at least 5.0 inches in diameter at breast height but smaller than sawtimber size, and of good form and vigor.

Saplings. — Live trees of commercial species 1.0 inch to 5.0 inches in diameter at breast height and of good form and vigor.

Saw-log portion. — Net volume of the bole of sawtimber trees from ground level to the point above which a saw log (according to Forest Survey definition) cannot be produced. The minimum saw-log top is 9.0 inches diameter outside bark for hardwoods. A saw log is defined by Forest Survey as a log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter inside bark of 8 inches for hardwoods.

Sawtimber trees. — Live trees of commercial species on commercial forest land containing at least a 12-foot saw log. Hardwoods must be at least 11.0 inches in diameter at breast height.

Timber cut. — Volume of timber products cut from live sawtimber and poletimber trees plus the logging residue that results from harvesting and transporting products from commercial forest lands.

Upper stem. — That part of the bole of sawtimber trees above the merchantable sawtimber top to a minimum top diameter of 4.0 inches outside bark or to a point where the central stem breaks into limbs.

Table 4. — Gross volume[1] of bolts and logs of different sizes

Top d.i.b. of piece, in inches	Length of bolt or log in feet															
	2		4		6		8		10		12		14		16	
	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.	Bd.ft.	Cu.ft.
4	-	0.2	-	0.4	-	0.5	-	0.7	-	0.9	-	1	-	1	-	1
5	-	.3	-	.6	-	.8	-	1	-	1	-	2	-	2	-	3
6	3	.4	5	1	7	1	10	2	10	2	15	3	15	4	20	4
7	3	.6	5	1	10	2	10	2	15	3	20	4	25	5	30	6
8	5	.7	10	1	10	2	15	3	20	4	25	5	35	6	40	7
9	5	1	10	2	15	3	20	4	30	5	35	6	45	8	50	9
10	5	1	15	2	20	3	30	5	35	6	45	8	55	9	65	11
11	10	1	20	3	25	4	35	6	45	7	55	9	70	11	80	13
12	10	2	25	3	35	5	45	7	55	9	70	11	85	13	95	15
13	15	2	25	4	40	6	55	8	70	10	85	12	100	15	115	17
14	15	2	30	4	50	7	65	9	80	12	100	14	115	17	135	20
15	20	3	35	5	55	7	75	10	95	13	115	16	135	19	160	22
16	20	3	40	6	65	9	85	12	110	15	130	18	155	22	180	25
17	25	3	50	7	70	10	95	13	125	17	150	21	180	24	205	28
18	25	4	55	7	80	11	110	15	140	19	170	23	200	27	230	32
19	30	4	60	8	95	12	125	17	155	21	190	26	225	30	260	35
20	35	4	65	9	100	14	135	18	175	23	210	28	250	33	290	39
21	40	5	75	10	115	15	155	20	195	26	235	31	280	37	320	42
22	45	5	85	11	130	16	170	22	215	28	260	34	305	40	355	46
23	45	6	90	12	140	18	185	24	235	30	285	37	335	44	390	50
24	50	6	100	13	155	19	205	26	255	33	310	40	370	47	425	55
25	55	7	110	14	165	21	220	28	280	36	340	43	400	51	460	59
26	60	7	120	15	180	23	240	31	305	39	370	47	435	55	500	64
27	65	8	130	16	195	25	260	33	330	42	400	50	470	59	540	69
28	70	9	140	18	210	27	280	35	355	45	430	54	510	64	585	73
29	75	9	150	19	230	29	305	38	385	48	465	58	545	68	630	79
30	80	10	160	21	245	31	325	41	410	51	495	62	585	73	675	84
31	90	10	170	22	260	33	350	43	440	55	530	66	625	78	720	89
32	95	11	185	23	280	35	375	46	470	58	570	70	670	83	770	95
33	100	12	200	24	300	37	400	49	500	62	605	75	715	88	820	100
34	105	13	210	26	320	39	425	52	535	65	645	79	760	93	875	107
35	110	14	220	28	340	41	450	55	565	69	685	84	805	98	925	113
36	120	14	235	29	355	43	475	58	600	73	725	88	855	104	980	120
37	130	15	250	30	380	46	505	61	635	77	770	93	905	110	1,040	126
38	135	16	265	32	400	48	535	65	670	81	810	98	955	115	1,095	133
39	140	17	280	34	420	51	565	68	710	86	855	103	1,005	121	1,155	140
40	150	18	300	36	445	54	595	72	750	90	900	109	1,060	128	1,220	147

1/ Cubic feet--peeled wood; board feet--International 1/4-inch rule.

ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
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Climatic Conditions Preceding Historically Great Fires in the North Central Region

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• RODNEY W. SANDO

MAR 30 1970

North Central Forest Experiment Station
Forest Service
U.S. Department of Agriculture

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Climatic Conditions Preceding Historically Great Fires in the North Central Region

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Weather conditions that increase the threat of forest fires are well known. Low precipitation and humidity, coupled with high temperature and maximum solar radiation, lower the forest fuel moisture and therefore increase the fire potential. Winds also play a part in this drying process. After ignition, wind force and direction are of great concern; high, variable winds make suppression difficult, and sometimes impossible.

The specific importance of each meteorological factor is not known for the climatic periods that preceded historically large fires. But we do know, for example, that drought — a condition induced by a combination of meteorological factors — has generally helped set conditions for large fires. Unfortunately, its exact role is unknown, for the term is usually used in a vague and qualitative sense. Palmer (1965) has compiled a partial list of definitions that have been used in drought studies, and he thereby points out the problem. Drought has been defined as:

1. A period with precipitation less than some small amount such as 0.10 inch in 48 hours (Blumenstock 1942).
2. A period of more than some particular number of days with precipitation less than some specified small amount (Great Britain Meteorological Office 1951).
3. A period of strong wind, low precipitation, high temperature, and unusually low relative humidity (Condra 1944).
4. A day on which the available soil moisture was depleted to some small percentage of available capacity (van Bavel and Verlinder 1956).
5. Monthly or annual precipitation less than some particular percentage of normal (McGuire and Palmer 1957).

The same problem of vague definition is evident in our knowledge of the relative importance of the other climatic parameters associated with large fires. Seasonal meteorological conditions leading to these events of the past are usually described by such phrases as: "The summer of 1881 was excessively dry and the drought had done its work . . . hot, dry August . . ." (Bailey 1882). "The summer had been deficient in rainfall. High temperatures, dry air, and light wind for almost 4 months previous" (Guthrie 1936). Holbrook (1960) presents some quantitive data in describing the climatic conditions before the 1894 Hinckley fire, but usually he uses descriptive terms for the other periods analyzed. As an example: "A drought had laid on the land from early May through September, with only one rain, 'a smart shower,' on July 8 to break it." Davis (1959), in reviewing 10 major historical fires, gives brief, definitive information in two cases, but usually describes a situation as: "Extremely hot and dry summer. No rain for months. Hot days with only moderate winds at time of fire." Wells (1968), in his book on the Peshtigo fire, analyzes some of the 1871 records at Milwaukee but finds the information less than satisfactory as it applies to the fire area and summarizes prefire conditions by ". . . it can be accepted that there was a serious drought and that the woods were unusually susceptible to fire."

Little detailed information exists on the characteristics of climatic conditions occurring before historical forest fires. In this paper we will attempt to quantitatively assess the "drought" conditions that preceded a number of great fires and to determine the climatic extremes referred to by such terms as "hot summer" and "low humidity." Sunshine records will also be examined, when available, and in some cases the general wind conditions and synoptic situations that immediately preceded these fires.

PROCEDURE

Selection of Fire Cases

For the purposes of this study, selected fires were restricted to Illinois, Michigan, Minnesota, and Wisconsin. This area is relatively homogeneous; the topography is mostly level, and during summer and autumn weather patterns are generally uniform.

Seven historically great fires were selected from the period 1870 to 1920 (table 1). No earlier fires were considered because of insufficient weather records. The Signal Service's[1] weather

[1] *The Signal Service preceded the Weather Bureau (until 1891) as the designated weather information agency of the U.S. Government (Whitnah 1961).*

Table 1. — The fires and their effects

Name of fire	Date	Acres burned	Lives lost	Reference
Peshtigo (Wis.)	Oct. 8, 1871	1,280,000	1,300	Wells 1968
Chicago (Ill.)	Oct. 8, 1871	1/2,240	200	Lincoln Library 1965
Lower Michigan	Oct. 8-10, 1871	2,500,000	--	Holbrook 1960
Michigan Thumb	Aug. 31-Sept. 5, 1881	1,000,000	169	Holbrook 1960
Hinckley (Minn.)	Sept. 1, 1894	2/160,000	418	Plummer 1912
Baudette (Minn.)	Oct. 7, 1910	300,000	42	Plummer 1912
Cloquet (Minn.)	Oct. 12, 1918	250,000+		Holbrook 1960
		or	538	
		1,280,000		Richardson 1919

1/Destroyed 17,450 buildings
2/Only forested acres given.

forecasting service was established in 1870, and such items as daily synoptic charts and monthly maps of United States precipitation totals were not issued prior to that time. Fires after the early 1920's were not included in this study because by that time forest protection became increasingly effective in the Lake States and it would be necessary to include fire control factors in this analysis.

The Chicago fire was also included in sections of this study because Signal Service records are available for most of the 1870-1871 period. The Chicago weather office burned during the Great Fire, but regular observations began at another nearby location just 7 days after the disaster.

All fires occurred during September or early October. Only late-summer fires were selected because the importance of individual climatic features is different during the various seasons. As an example, the presistence of winter snow might play an important part in spring fires. By fall, however, effects of snow cover should be diminished. Even with the fires restricted to September-October, there could still be a seasonal transition bias in the data.

Determining the actual number of acres burned in each of the fires is often difficult. The figures in table 1 are our best estimate from an extensive review of the literature. The 1894 Hinckley disaster destroyed the smallest forested area — 160,000 acres. All others burned a minimum of a quarter million acres. Human lives were lost on all fires — 1,300 at Peshtigo in 1871.

Early Weather Stations and Records

Weather data taken at observation sites in or near the historic fire region were obtained mostly from original records or from published U.S. Weather Bureau climatic material (1932-1936). All data are presented for the season or year of the fire and, in the case of precipitation, for the previous year. The locations of the weather observation sites are shown in figure 1.

Because of the extremely large amount of burned acreage in Lower Michigan during October 1871, we used four State stations to establish the fire-climatic pattern: Detroit, Grand Rapids, Lansing, and Thunder Bay (near Alpena). The fires of 1871 stayed well north of Detroit, but destroyed Holland (less than 25 miles from Grand Rapids) and threatened Lansing and Alpena.

In the Peshtigo region, both Embarrass and Sturgeon Bay had well-kept records during the early 1870's. Embarrass precipitation observations were continuous from 1864 to 1892. However, there appears to be either a local anomaly at the immediate site or there was an instrument exposure problem. Surrounding weather stations — such as Green Bay, Shawano, and New London — have normal precipitation amounts of near 30 inches per year, while Embarrass averaged over 40 inches during its period of record. In order to have a standard record period from which to measure precipitation deviations in the various years, all precipitation data (except for Embarrass) have been based on the period from 1931 to 1960 insofar as possible. Because of the bias in the Embarrass data, this station's deviations are expressed in terms of the period over which the record was kept.

Obtaining temperature data during this early period was more difficult than obtaining precipitation information. Apparently no station had maximum and minimum thermometers during the early 1870's. Average daily temperatures during much of the 1800's were computed from a number of air temperature readings taken at specific times during the day. Because of this fact, the temperatures used in this paper are usually computed as departures from a period of years during which the specific fire occurred.

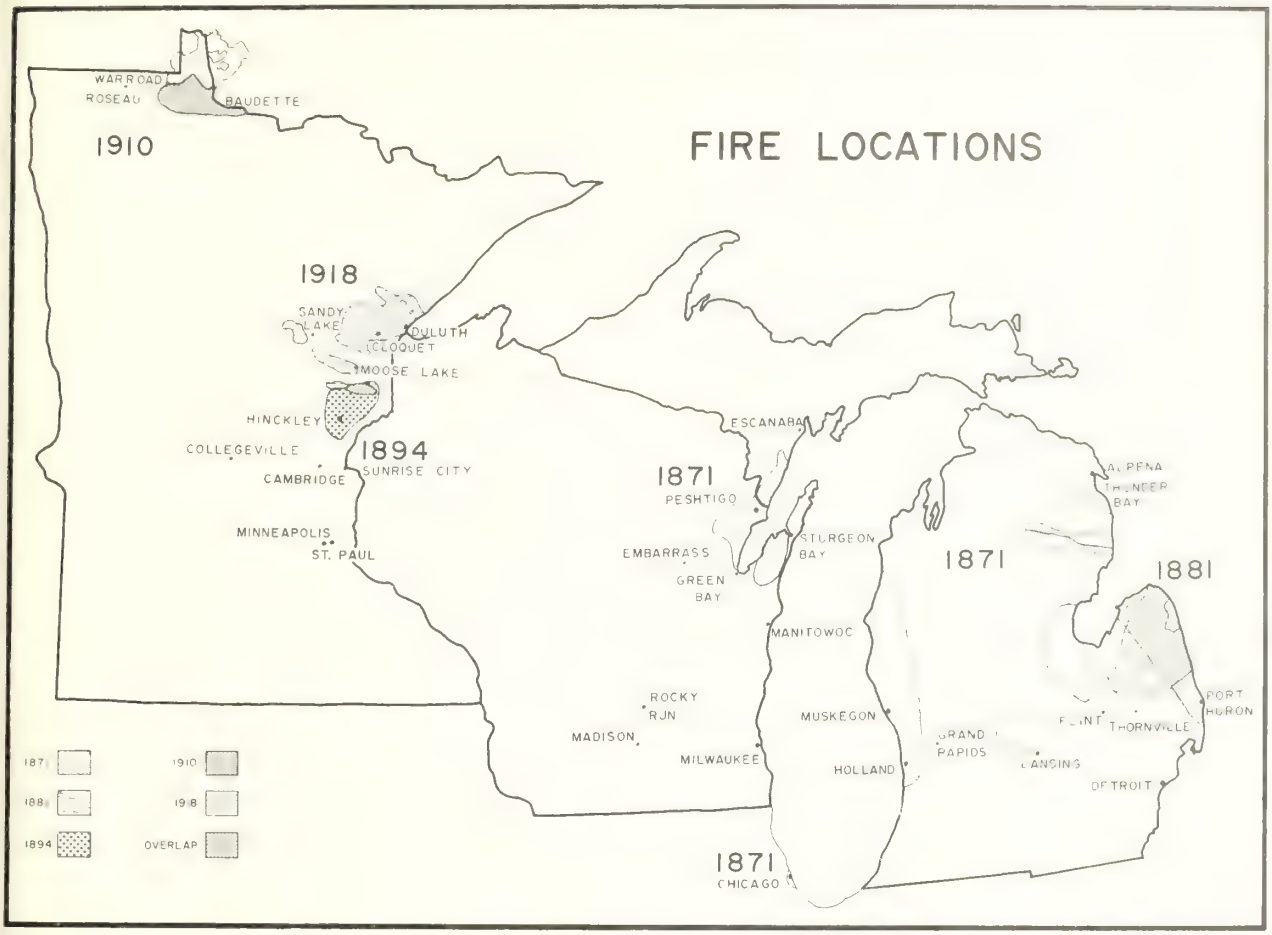

FIGURE 1. — Location of the burned areas and the nearby weather-observation sites operating at the time of the fire. The 1894 and 1918 fire areas overlap, as do the Michigan 1871 and 1881 areas.

Weather records were taken at Thornville and Port Huron for a number of years preceding the 1881 Michigan Thumb fire. Thornville is close to the fire region; Port Huron, although somewhat farther away, provided maximum and minimum temperatures for that period.

By the time of the Hinckley fire of 1894, a number of well-run cooperative weather stations were established in eastern Minnesota. Collegeville, although some distance to the west of the main fire area, and St. Paul, to the south, were included in this study because of the excellence and duration of their observations. Cambridge and Sandy Lake are nearer to the main fire region.

The Baudette fire of 1910 burned the weather station in that city. Therefore, Roseau observations were used to complete the record for October.

The fire of 1918 burned Cloquet, but the cooperative weather station was not lost. Weather observations are therefore continuous for that city. Nearby Duluth was and still is a Weather Bureau first-order station. The more complete instrumentation at this station (i.e., a sunshine recorder, wind equipment, etc.) made possible a more complete reconstruction of the weather conditions preceding and during this fire.

Some data from other weather stations were used in specific instances during the course of this study. As an example, data from Madison, Milwaukee Manitowoc, and Rocky Run, Wisconsin, were used to establish the extent of rainfall departures from normal before the 1871 Peshtigo and Chicago fires, and were also included in the precipitation averages for one graph.

CLIMATIC VARIABLES

Precipitation

Precipitation graphs for 15 stations over a 2-year period are given in figure 2. The stations are

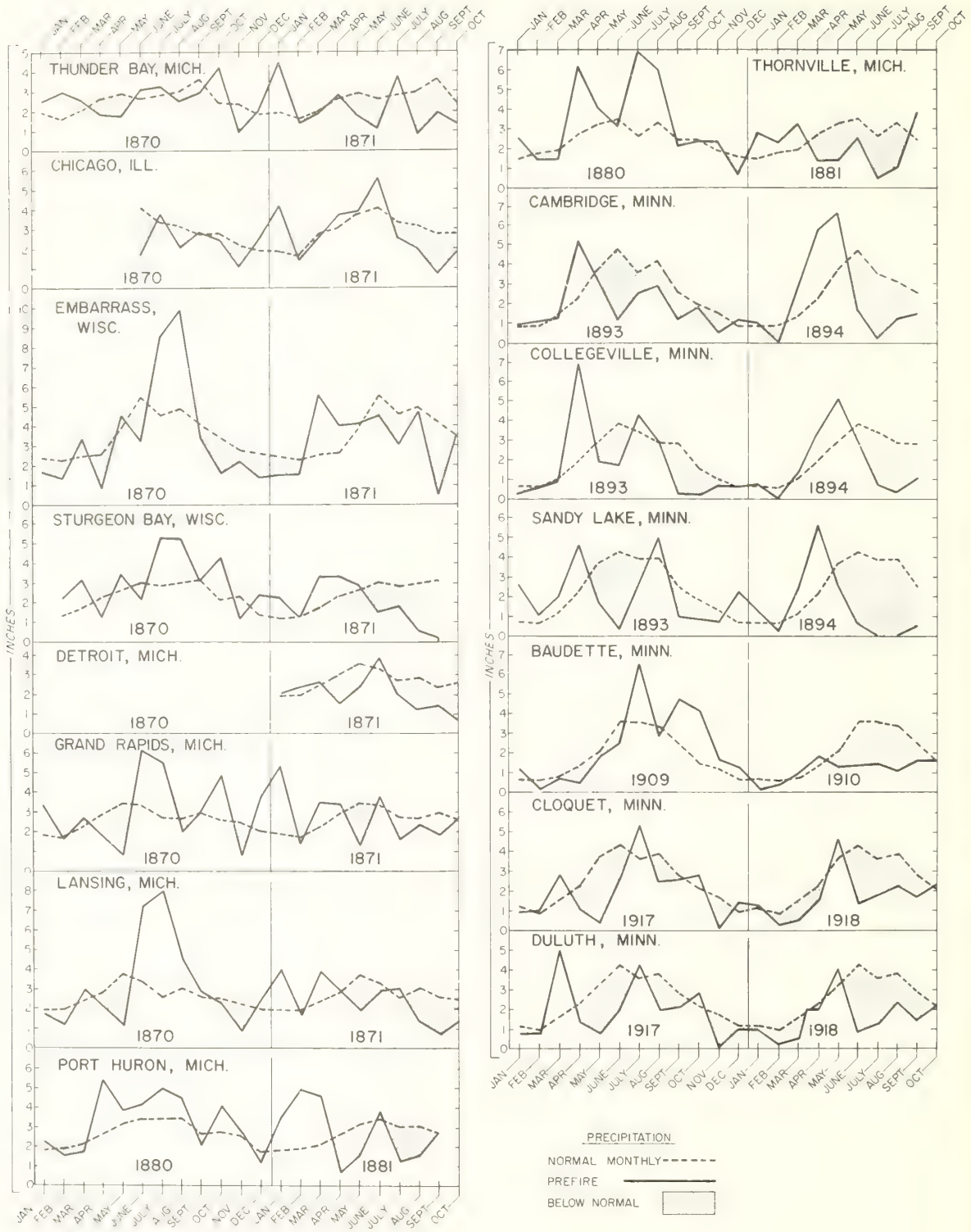

FIGURE 2. — Departure from normal monthly precipitation amount during the 2 years preceding the 1871, 1881, 1894, 1910, and 1918 fires. The normal monthly precipitation is delineated by a broken line, the prefire precipitation by a solid line. Shaded areas represent periods when precipitation was below normal.

arranged in this manner to show the similarities between records in the individual prefire months. Monthly normals are plotted for each station, and superimposed on these normals are the monthly precipitation values during the fire years.

Present-day specialists usually view drought from the standpoint of departure from normal precipitation, as does the American Meteorological Society (Huschke 1959). The rigorous classification scheme of Palmer (1965) is built on a definition of drought as "a prolonged and abnormal moisture deficiency." In our analysis of precipitation preceding large fires, this definition is used as a reference point.

Questions pertinent to this study are: (1) Was the precipitation amount below normal, and, if so, (2) was the abnormal situation prolonged? The first question is answered by simply looking at the graphs; the second is more difficult. In the treatment of agricultural drought, Palmer (1965) showed an example in which his method of evaluation produced incipient to extreme drought from July 1932 to October 1940 in western Kansas. However, the fire drought problem is mostly concerned with moisture loss in dry fuels rather than stress effects upon vegetation growth. Therefore, we will confine consideration of drought to the fire year.

Prolonged and abnormal moisture deficiency began in Lansing and Grand Rapids in May 1871, in Sturgeon Bay in June, and in Chicago in July (fig. 2). It began in Port Huron and Thornville in April 1881, in Sandy Lake in May 1894, in Cambridge and Collegeville in June 1894, and in Baudette in May 1910. In some instances, precipitation was slightly above normal during one month of the period, but the overall seasonal pattern indicates a large precipitation deficit. The beginning of prolonged moisture deficiency is more difficult to establish at the other stations; thus there may be some disagreement on the starting months at these sites.

U.S. War Department (1871) monthly precipitation maps indicate near- or above-normal moisture throughout Michigan in 1870 and early 1871. If we assume that Detroit also experienced these conditions, prolonged moisture deficiency began there in April 1871. Thunder Bay had heavy precipitation in January 1871, then near-normal conditions for 3 months. Fairly low amounts fell in May and June, however, and May was selected as the beginning month of low rainfall.

The Embarrass record shows a dry autumn in 1870 as well as a below-normal winter snowfall. However, March and April had well-above-normal rains. We matched the data with the Sturgeon Bay pattern and designated June as the beginning month of the dry spell. The 1918 Cloquet and Duluth records present a problem, because severe drought may well have begun as early as the autumn of 1916 in that region and continued until the October 1918 fire. To avoid possibly overestimating the importance of moisture deficit, however, we considered only the season in question and assumed an 8-month dry period. Therefore, the periods of prolonged and abnormal departures were as short as 3 months before the Chicago and Hinckley fires, and as long as 8+ months before the Cloquet disaster.

A comparison of the total amount of precipitation that fell during these selected dry periods and the lowest amounts ever recorded for these periods shows that almost all stations (except the Michigan 1871 sites) were near their all-time low precipitation totals during the prefire months (table 2). In fact, five stations recorded their all-time low during these months.

Dividing the length of weather record by the number of times rainfall has been as low or lower than it was in the prefire period gives the return period for the prefire moisture deficient conditions in that area. As an example, Baudette had May through September rainfall totals of less than 6.60 inches only once during its 58-year weather record. Therefore, drought conditions (based on 1910 rainfall amounts) occur on the average of once every 29 years in Baudette. Duluth never experienced a February through September precipitation total less than the 1918 amount of 12.67 inches; therefore, its prefire drought recurrence is 96 years, the weather record length from its beginning through 1968. *It is evident that all but the 1871 Michigan data show one station in each fire region as having a very low recurrence for extreme prefire drought conditions.*

The relative severity of drought conditions preceding each fire is shown in figure 3. The 1894 prefire condition was the most serious and the 1871 Michigan condition the least serious. There is a problem with the intermediate ranking in that it depends on interpreting the importance of time vs. amount of precipitation. But if we total the precipitation for a number of stations for periods of 15, 30, 60, 90, and 150 days preceding the start of a specific forest fire (fig. 4) then the problem can be viewed in a different way. Here the amounts were computed as a departure from normal, and the totals of all stations used in each forest fire situation were added together and averaged for each time period. The usual case was very little rainfall for 15 days before a conflagration. There were, however, some exceptions. Port Huron recorded a total of 0.90 inch and Thornville 0.69 inch of rain on August 31 and September 1 prior to the Michigan Thumb fire. In 1918 Cloquet received light rain on the eighth through the fourth days preceding the fire, but the greatest 24-hour total was 0.15 inch, and the 5-day accumulation amounted to only 0.32 inch. There was no precipitation during the 10-day periods before the other fires.

The problem of trying to determine the severity of prefire climatic conditions when restricted to

Table 2. — Comparison between prefire precipitation and normals

Year	Station	1 Months of drought preceding fire	2 Total precipitation during months of drought	3 Lowest precipitation amount ever recorded during same period of months	4 Number of times total precipitation has been less than amounts given in column 2	5 Length of reliable station record[1]	6 Normal precipitation amount during months in column 1
			Inches	Inches		Years	Inches
1871	Detroit	6 (April-Sept.)	12.35	10.89	6	96	17.75
	Grand Rapids	5 (May-Sept.)	11.08	7.46	11	96	15.18
	Lansing	5 (May-Sept.)	10.21	8.25	7	103	15.30
	Thunder Bay	5 (May-Sept.)	9.58	8.08	5	96	15.08
	Chicago	3 (July-Sept.)	5.27	4.01	3	96	9.26
	Embarrass	4 (June-Sept.)	12.54	10.98	1	28	18.86
	Sturgeon Bay	4 (June-Sept.)	4.75	4.75	0	80	12.12
1881	Port Huron	5 (April-Aug.)	9.15	7.29	8	92	15.38
	Thornville	5 (April-Aug.)	6.75	6.75	0	90	15.23
1894	Cambridge	3 (June-Aug.)	3.09	2.83	1	75	12.34
	Collegeville	3 (June-Aug.)	4.03	3.19	1	75	10.07
	Sandy Lake	4 (May-Aug.)	3.28	3.28	0	75	15.72
	St. Paul	3 (June-Aug.)	2.00	2.00	0	128	10.85
1910	Baudette	5 (May-Sept.)	6.60	6.36	1	58	14.86
1918	Cloquet	8+ (Feb.-Sept.)	14.20	13.52	1	96	23.19
	Duluth	8+ (Feb.-Sept.)	12.67	12.67	0	96	22.71

[1] In some cases records at the indicated station were combined with those at a nearby station to fill in missing years and give the longest possible record. As an example, the St. Paul data have been combined with early Fort Snelling records and more recent Minneapolis observations to give the longest historical series of weather records west of the Mississippi River.

evaluation over a rigid time period is illustrated in figure 4. As an example, the departures in five of the six fires very little over 60 and 90 days. But in the sixth case — the Hinckley fire — the departure from normal is much greater than the departures shown for the other fires over these same periods. Conversely, if we examine precipitation records for 150 days preceding the fires, we see that the Hinckley region shows the smallest departure from normal precipitation. A curve showing the average precipitation departure for the six fires is included on the graph, but its usefulness is questionable because of the high variation over any specific time interval among the fires.

Examining departure from normal amount is, of course, only one way to view the contribution of reduced precipitation to large fires. Frequency of precipitation may also be important, because frequent wetting of available fuel should reduce the fire hazard. Consequently, the number of days that had 0.10 inch or more of precipitation was also computed for each fire region. Again, the time intervals examined were 15, 30, 60, 90, and 150 days preceding each fire. The composite results appear random; for instance, the rainfall frequency was extremely low over almost all time intervals before the 1894 Hinckley fire. Rainfall frequency for the 15-day period preceding the Baudette, 1871 Wisconsin, and 1871 Michigan fires was very low, while frequencies for the 60-day and longer periods were more than 50 percent of expected.

Rainfall frequencies preceding the Cloquet and Michigan Thumb fires, except for the 30-day interval at Cloquet, were more than 70 percent of the expected. Apparently there was nothing unusual about the rainfall frequency distributions before these two fires.

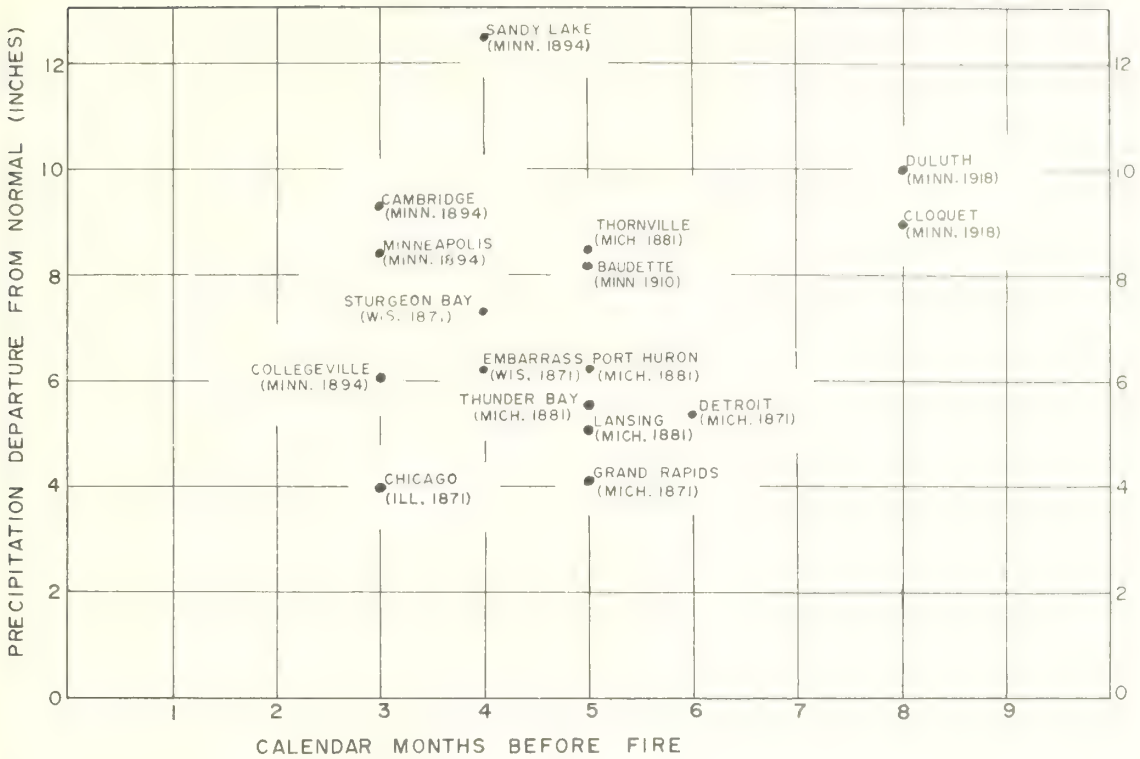

FIGURE 3. — Severity of north-central region fires ranked by prefire precipitation deficit. Sandy Lake, Minnesota, recorded by far the worst conditions preceding the 1894 Hinckley fire. The well-grouped Michigan stations recorded the mildest departure from normal before the 1871 fires.

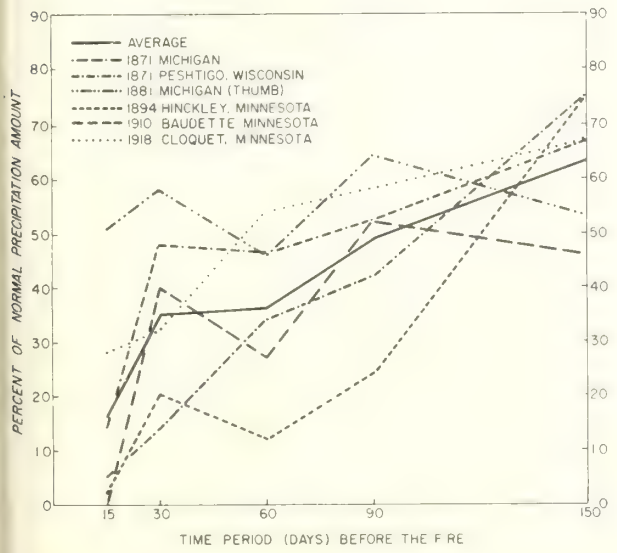

FIGURE 4. — Percent of normal precipitation amount. Data calculated for 15-, 30-, 60-, 90-, and 150-day periods preceding the fire.

Temperature

The literature on climatic conditions preceding large fires may lead one to believe that the terms "hot" and "dry" are nearly synonomous. For instance, Bailey (1882) described the Michigan Thumb region in the following way: "In September no penetrating rain had fallen for almost two months. . . . The swamps had been burned to hard clay by the sun, fiercer in its heat than it had been for years before." However, an examination of the monthly mean departures from normal temperatures at a number of stations preceding the fires shows this contention to be questionable (fig. 5). The U.S. Weather Bureau (1968) considers deviations of more than 0.7° to 1.3° F. to be above or below normal at most Lake States stations during the summer. To be classed as much above or below normal, the deviation must be greater than from 2.5° to 4.7° F. depending on the summer month and station. It is interesting to note that there were above-normal temperatures preceding all the fires, but these often occurred early in the fire year. As an example, strategic regions of Michigan, Illinois, and Wisconsin all had above-normal

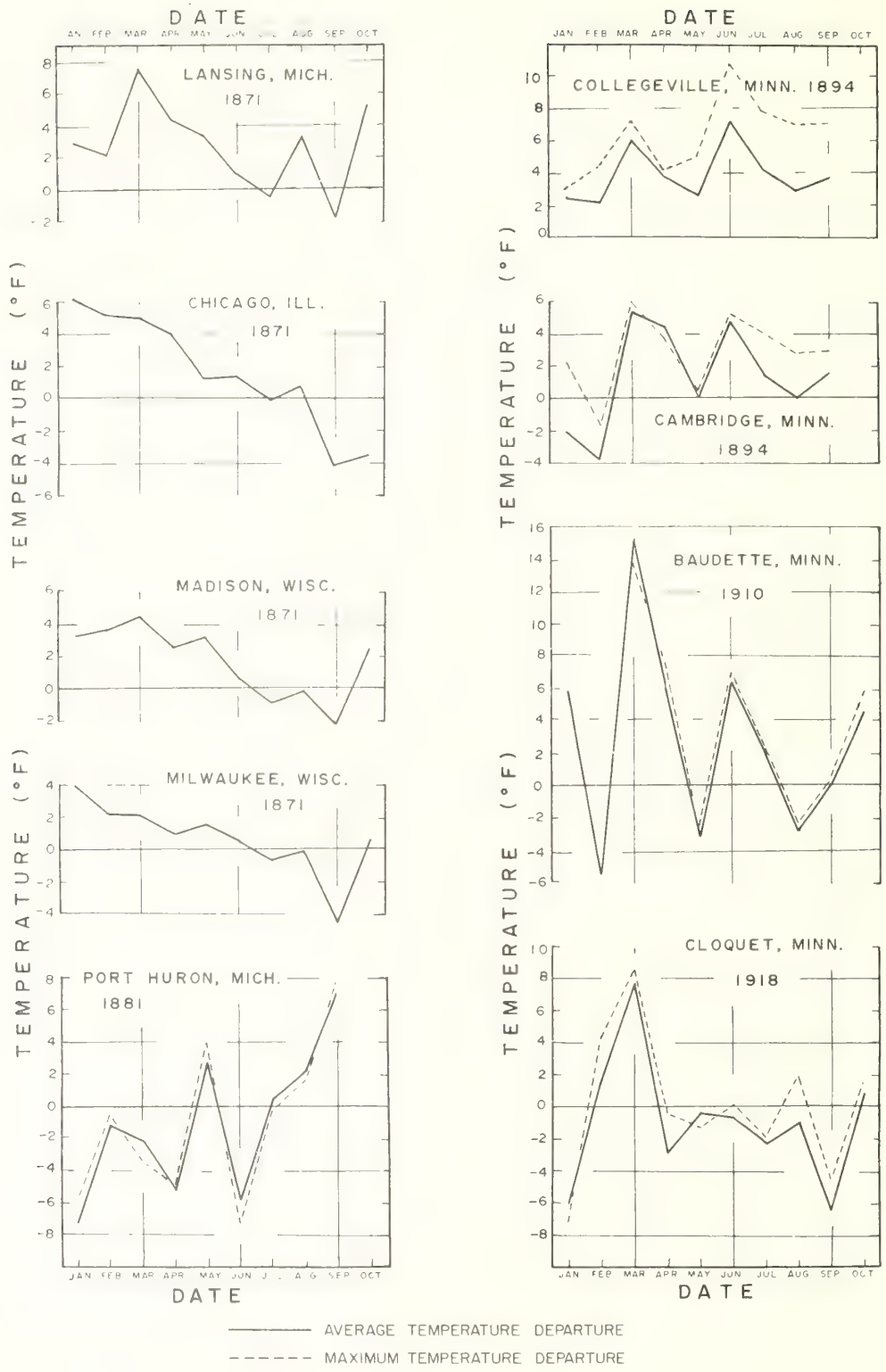

FIGURE 5. — Departures of monthly temperature from average during the year of the fire.

temperatures through the first half of 1871. However, their temperatures over the dry period were below normal in most cases (table 3). During the month preceding the fire (table 3), all stations experienced below-normal temperatures in 1871.

The 1894 fire came closest to having a hot-dry prefire climate. As shown in table 2, southeastern Minnesota experienced the lowest June-July-August precipitation total (as observed in St. Paul) throughout a 128-year record. The St. Paul 1894 temperature average for these 3 months has been exceeded only eight times over the length of the station's temperature record (1819 to 1968). Three of these eight occurred in the 1820's when an unknown method was used to compute average temperature. Therefore, 1894 does fit the concept of extremely hot and dry conditions preceding a serious fire situation. In contrast to the 1894 events are the Cloquet prefire conditions where most of the 1918 summer was cool and the temperature during the month preceding the fire was 6.5° F. below the expected.

Computing average temperatures is, of course, only one way of examining the effects of temperature. If the nights were unusually cold and the days unusually hot during these prefire periods, the average temperature might be the same as it would be during periods having only small amplitudes in the diurnal range. Therefore, average temperatures may not accurately reflect daytime drying conditions under high maximum temperatures. The deviation of the maximum temperatures from normal shows the 1894 hot-dry situation to be even more intense than did the deviation of the average temperature (fig. 5). However, this does not appear to be true for the other fires.

We also evaluated temperature by computing the number of days in each month that the daily maximum temperature reached or exceeded 90° F. during the prefire period (table 3). Temperatures in 1894 again stand out as unique. The Hinckley region recorded four to five times the number of hot days that it normally has, and southeastern Minnesota recorded temperatures above 90° F. on half the days in July. Therefore, regardless of the method used to analyze temperature, 1894 stands out as an abnormally hot season.

However, the number of days recording temperatures of 90° F. or higher was less than normal before the Cloquet and Michigan Thumb fires. Therefore, this aspect of temperature did not appear to have had an effect on prefire developments. The Baudette region experienced three times the expected number of days of high maximum temperature before its fire, but almost all of these days occurred during the latter half of June, more than 3 months before the fire began. *Looking at long-term prefire temperature data, we can conclude that abnormally high temperatures are not a necessary prerequisite to large fires.*

When we examine temperatures within 10 days of the fire, however, a somewhat different pattern emerges (table 4). Only the 1871 daily temperatures follow much the same trends shown for longer periods preceding the fires. In 1881 temperatures were 7° above normal for the 10 days preceding the fire, and in 1894 they were 10° above normal. In 1910 temperatures were 12° above normal, and in 1918 they were slightly above normal. It would appear, consequently, that if there is a conflagration reaction to temperature, *it is often a short-term response.*

Table 3. — Average monthly temperature and number of days temperature was 90°F. or above

Year	Station	Average monthly temperature departure during months of drought preceding fire	Average temperature departure during month preceding fire	Number of days temperature was 90° F. or above[1/]										Ratio 0:E
				June		July		Aug.		Sept.		Oct.		
				O	E	O	E	O	E	O	E	O	E	
		°F.	°F.											
1871	Lansing	+1.1	-1.6	--	--	--	--	--	--	--	--	--	--	--
	Chicago	-1.1	-4.0	--	--	--	--	--	--	--	--	--	--	--
	Madison	- .9	-2.0	--	--	--	--	--	--	--	--	--	--	--
	Milwaukee	-1.0	-4.3	--	--	--	--	--	--	--	--	--	--	--
1881	Port Huron	-1.1	+2.1	0	3	3	6	7	3	2	2	--	--	12:14
1894	Collegeville	+4.9	+3.0	10	2	16	3	7	2	3	1	--	--	36:8
	Cambridge	+2.1	± .0	7	1	15	2	6	2	2	1	--	--	30:6
1910	Baudette	+ .6	+ .2	9	1	3	2	0	1	0	0	0	0	12:4
1918	Cloquet	- .5	-6.5	0	1	1	1	1	1	0	0	0	0	2:3

[1/] O = occurred; E = expected.

Table 4. — Temperature 10 days before the fire [1]
(In degrees F.)

Year	Station	September 29	30	October 1	2	3	4	5	6	7	8	10-day average
1871	Grand Rapids	55	67	72	69	69	63	73	54	62	76	66
	Grand Rapids normal	69	69	68	68	68	67	67	66	66	65	68
	Lansing	61	69	65	78	69	67	70	80	54	62	68
	Lansing normal	67	67	67	66	66	66	65	65	64	64	66
	Thunder Bay	56	62	62	60	60	56	52	49	54	56	57
	Alpena normal	62	62	62	61	61	61	60	60	59	59	61
	Chicago	64	78	76	76	84	70	76	52	70	85	73
	Chicago normal	72	71	71	70	70	70	69	69	69	68	70
	Sturgeon Bay	61	64	62	64	70	58	52	51	60	63	61
	Manitowoc	64	62	67	70	75	60	53	50	65	65	63
	Green Bay normal	72	71	71	70	70	70	69	69	69	68	70

Year	Station	August 27	28	29	30	31	September 1	2	3	4	5	10-day average
1881	Port Huron	86	80	90	94	94	79	74	82	85	95	86
	Detroit normal	80	79	79	79	79	78	78	78	78	77	79

Year	Station	August 23	24	25	26	27	28	29	30	31	Sept. 1	10-day average
1894	Cambridge	90	82	84	89	85	88	72	77	83	94	85
	Collegeville	92	82	89	94	89	86	78	81	79	95	87
	St. Cloud normal	79	78	78	77	77	77	77	76	76	75	77

Year	Station	September 28	29	30	October 1	2	3	4	5	6	7	10-day average
1910	Baudette (Roseau)	74	72	77	70	71	64	71	59	68	76	70
	International Falls normal	60	60	59	59	58	58	58	57	57	56	58

Year	Station	October 3	4	5	6	7	8	9	10	11	12	10-day average
1919	Cloquet	60	58	58	53	50	67	70	72	69	75	63
	Duluth	60	53	57	48	49	67	69	73	52	76	60
	Duluth normal	59	59	59	58	58	57	57	57	56	56	58

[1] The 1871 temperatures were taken at 2:00 p.m. EST. All other data are maximum temperatures, including normals.

Potential Evapotranspiration and Water Balance

Up to this point weather variables have been discussed as separate entities, whereas in nature they interact. Therefore, with both precipitation and temperature data tabulated, we now can more fully describe their importance by looking at the soil-water balance.

There are a number of methods available for computing time distributions of soil-water balance. The advantages and disadvantages of the various methods have been discussed by Zahner (1956), Palmer (1965), and Chang (1968). For this study the Thornthwaite method was chosen because we have the computational information needed. This method requires (1) mean air temperature and total precipitation, (2) the necessary conversion and computational tables, and (3) information on the water-holding capacity of the depth of soil for which the balance is to be computed. We have the mean monthly temperature and precipitation data, the necessary conversion and computational tables are provided in Thornthwaite and Mather (1955, 1957), and information on types of soil in the fire regions was extracted from a Wisconsin Agricultural Experiment Station soils classification bulletin (1960). Values for available water-storage capacity and wilting coefficients of forest soils are given in Smith and Ruhe (1955) and Blake *et al.* (1960).

There are disadvantages in the Thornthwaite method. Bias may develop because of neglect of solar radiation, relative humidity, and wind, because they all affect the evapotranspiration term. However, if one uses time periods of sufficient length (2 weeks or longer), average percent absolute error is no higher than 10 to 15 percent (Palmer 1965). Another problem appears when snow or heavy rain enters into the calculations, because these types of precipitation often result in runoff. The method, however, assumes that all precipitation enters the ground and that there is no runoff until the soil is at saturation. Therefore, regardless of the previous year's moisture situation, our calculations produced fully saturated soils after snowmelt each spring. But because we are examining late-summer fires, this bias is eliminated by the time we reach the main period of concern.

Soil-water calculations were made for 3-foot soil depths, the upper rooting depth of bromegrass. When the wilting point of this type of vegetation has been exceeded, large amounts of fine fuel become cured, setting the stage for later serious fire situations. Computations were based on the supposition that all the soils in the fire regions have a 6-inch water-holding capacity and that the vegetation wilting stage is reached when the water amount decreases to below 1.8 inches. Because of the transitional changes and complexities of soil types throughout any region, these are, of course, average figures.

Drought profiles based on the soil-water calculations are shown for one station from each fire year (fig. 6). The upper curve is based on monthly normal temperature and precipitation and depicts the usual seasonal variation of the soil's water supply. While Michigan's vegetation is usually near the wilting stage in September, it is unusual for east-central Minnesota's vegetation to be subjected to extreme drying.

The water-holding capacity of the soil in Minnesota has also been examined by Blake *et al.* (1960) using Penman's (1948) evaluation methods on a daily basis. Blake found that the expected number of drought days is much lower in east-central Minnesota than in the rest of the State. It is about half the number of days expected in the Baudette region. This is almost the same ratio shown between these stations in figure 6. At the low value of the Baudette normal curve there is a departure of about 3.5 inches from field capacity levels. At Cloquet the normal departure from field capacity is less than 2 inches.

The departures from the normal moisture conditions and length of time in wilt again point out the problem of drought definition (fig. 6). The graphs indicate that Baudette was below the defined wilting stage for over 2½ months. The period was about 2 months at the Michigan and Wisconsin stations in 1871, and at the Cloquet station in 1918. The shortest wilt stage was recorded for the 1881 and 1894 fire seasons — 1⅓ months. On the other hand, if we look at the prefire departures from normal water-holding amounts, then the 1894 drought was much more severe than any of the others, with a water departure of over 3 inches from the expected. The Lansing 1871 departures are the least spectacular, the greatest prefire departure from expected being only 1⅓ inches. The reason for this apparent conflict is again obvious: Wilt is a more normal condition at some places than it is at others.

Sunshine Duration

As stated earlier, the neglect of certain meteorological variables might cause erroneous results when computing the soil-water balance. For instance, increased solar radiation contributes to increased evapotranspiration. However, it is impossible to use solar radiation directly in this analysis, for it is measured at relatively few stations and these records are short-term. In contrast, the less important but more easily measured variable, duration of sunshine, has been recorded at many stations, with some records extending back to the 1890's. Baker and Haines (1969) have shown that

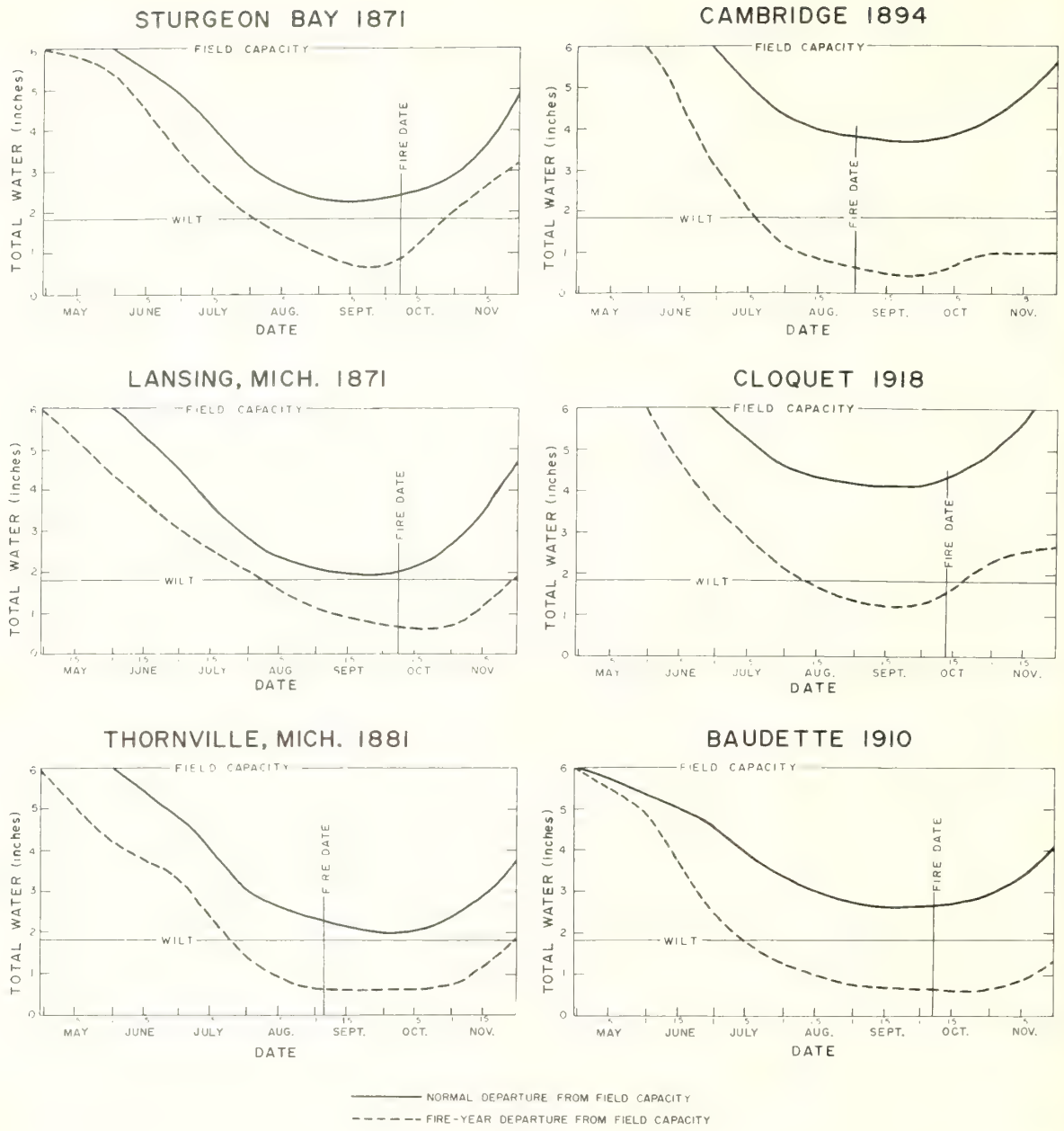

FIGURE 6. — Agricultural drought profile during the seasons of the Peshtigo, 1871 Michigan, 1881 Michigan Thumb, Hinckley, Cloquet, and Baudette fires. Data were computed for a 3-foot soil depth, assuming a 6-inch water-holding field capacity and a 1.8-inch wilt threshold value.

a high correlation exists between the two terms; therefore, available sunshine duration records taken during the fire years are presented in lieu of solar radiation tabulations (table 5).

The information recorded at observation sites during 1894, 1910, and 1918 shows that well-above-normal sunshine prevailed during the early portion of these seasons. Except during May 1918, every monthly average through July exceeded the expected percentage. There was a small minus departure in August 1894 preceding the Hinckley fire, but a plus departure in the month preceding the 1918 Cloquet disaster. However, an added factor may have entered into the Hinckley record. The

Table 5. — Departure from expected sunshine duration

(In percent)

Year	Station	March	April	May	June	July	Aug.	Sept.	Oct.
1894	Collegeville	--	--	+1	+16	[1]/+22	-4	-1	--
1910	Collegeville	--	--	+17	+16	+11	±0	+9	+11
	Devils Lake (N. Dak.)	+15	+11	+8	+17	+9	-7	-1	+7
1918	Duluth	+9	+13	-9	+13	+4	+7	+9	-9

[1]/ Only 10 days of record available in July. Supporting data indicate the value is probably closer to +10 to 15 percent.

sunshine instrument depends upon a certain intensity of solar radiation for activation. The Sunrise City, Minnesota, U.S. Weather Bureau observer states on his August 1894 form, "Most of the month has been clear and very smoky so one could look at the sun without smoked glass." Perhaps, then, smoke caused diminished sunshine at Collegeville in that month.

Evidence is somewhat contradictory during August and September preceding the Baudette fire. The Devils Lake, North Dakota, record shows percentages below the expected, while Collegeville shows percentages at or above the expected. However, the percentage of Clear Sky Charts (U.S. Weather Bureau 1910) for these 2 months places Baudette in the same regional pattern as Devils Lake; consequently, the Devils Lake record is probably more representative. The overall pattern that emerges from our somewhat scanty sunshine percentage data indicates above-normal solar radition through spring and summer, but a tendency toward near-normal reception during the month before the fire. Thus, above-normal sunshine duration during the prefire periods substantiates our previous drought estimates.

Relative Humidity

Relative humidity is, of course, most critical immediately before and during the fire, but it may also have a long-term effect on coarse fuels. Therefore, the departures of average monthly relative humidity from expected, especially the month-to-month trends, are significant (table 6).

Table 6. — Departure from expected monthly relative humidity

(In percent)

Year	Station	Local time of observation	March	April	May	June	July	Aug.	Sept.	Oct.
1871	Ann Arbor	2:00 p.m.	-6	-2	+4	+11	+7	+7	+5	-2
	Chicago	1:00 p.m.	+11	+8	+15	+10	+11	+10	-9	-18
	Madison	1:00 p.m.	-1	-7	-3	-6	-8	-2	-16	-22
1881	Thornville	2:00 p.m.	+15	+1	+1	+9	+3	-3	+2	--
1894	Duluth	7:00 p.m.	--	+17	+3	-8	-13	-5	-12	--
	Collegeville	7 a.m., 7 p.m.[1]/	--	--	--	±0	-10	-3	-10	--
1910	Devils Lake	7 a.m., 7 p.m.[1]/	-11	-9	-6	-16	-13	-6	+3	-4
	Duluth	7:00 p.m.	-10	+1	-10	-18	-13	-4	-4	-6
1918	Duluth	12:00 noon	-8	-6	+7	-6	-1	±0	-11	-7

[1]/ Mean of two observations.

The average monthly relative humidity was below the expected throughout much of the 1894, 1910, and 1918 fire seasons. We have seen that monthly temperature was not abnormally high in 1910 and 1918 prefire periods, but diminished atmospheric moisture seems to have contributed to the explosive fire situation.

Long-term humidity effects apparently had no bearing on the 1881 Michigan Thumb fire but most certainly did in the Wisconsin-Illinois outbreaks of 1871. Although the Ann Arbor 1871 records show nothing of significance, the Madison and Chicago observations are interesting. The fact that Chicago recorded above-average and Madison below-average humidity from March to August seems to indicate something unusual in one of the records. Large plus departures at Chicago may be at least partly the result of inappropriate normals. However, the interesting facet of the data is the lowered relative humidity departures from August to October at both stations. At Chicago there was a drop of 28 percent in the departure from expected between August and October, and at Madison a 20-percent drop — a phenomenal drying of the air covering this region. This is, of course, reflected in the actual humidities recorded at these stations in the days preceding the fires (table 7).

Humidity was extremely low preceding the Wisconsin 1871 fire, with Chicago recording 1:00 p.m. humidities in the 20's or 30's for 6 of the 10 days before the fire, and Milwaukee and Madison recording humidities of 13 percent within a week of the outbreak. Afternoon humidities for other years are also included in table 7 for comparison.

Table 7. — Relative humidity 10 days before the fire

(In percent)

Year	Station	September		October							
		29	30	1	2	3	4	5	6	7	8
1871	Chicago[1/]	74	38	27	27	44	49	36	44	27	24
	Madison[1/]	18	26	18	26	13	32	37	22	21	24
	Milwaukee[1/]	79	54	27	33	13	64	56	49	34	28
	Ann Arbor[1/]	40	31	42	48	45	60	43	38	47	40

Year	Station	August					September				
		27	28	29	30	31	1	2	3	4	5
1881	Thornville[1/]	56	40	36	36	40	73	62	55	55	32

Year	Station	October									
		3	4	5	6	7	8	9	10	11	12
1918	Duluth[2/]	36	94	100	74	90	33	26	24	84	31

[1/] Observations at 2:00 p.m. EST.
[2/] Observations at 1:00 p.m. EST.

Nonweather Factors

The extreme behavior exhibited by all the fires studied appears to have been largely due to unusual weather conditions; however, nonweather factors also contributed to the situations. It is important to note that all of the fires occurred during the period when the forest land in the Midwest was being actively logged and converted to agricultural land. As a result, settlers were dispersed throughout the countryside and large areas of logging residue were common. The extent to which the slash accumulation contributed to the behavior of the fires is unknown; however, the Hinckley and Peshtigo fires burned large logged-over areas (Wilkinson 1895, Brown 1894, Wells 1968). On the other hand, the Cloquet fire burned an area where little, if any, active logging was being carried out (Richardson 1919).

Bailey (1882) stated that one of the principal causes of the Michigan Thumb fire of 1881 was the large acreages of dead timber left standing

from former fires and the large areas of windfalls and slashings.

Fire behavior is largely determined by interactions of fuel, weather, and topography (Davis 1959). However, behavior of these mass conflagrations was greatly influenced by one additional factor — ignition. In all the fires studied, it is well documented that there were many ignition points when extreme fire behavior began. Robinson (1872) wrote, "For weeks preceding the Peshtigo fire, fires were sweeping through the countryside," while Bailey (1882) stated that in the days of early August 1881, fires were burning everywhere and no attempts were made to control them. According to Wilkinson (1895), fires were burning in the Hinckley area as early as July. Fisher (1918) and Richardson (1919) both state that for several days before the Cloquet fire there had been numerous brush and peat bog fires burning. The map of the Cloquet fire (fig. 1) clearly shows that the fire originated from several points and large areas were burned as a result.

Synoptic Patterns

The series of events leading to these great fires might be compared to the steps involved in firing a weapon. A large amount of fuel was usually available before the fire; this would be analogous to a rifle shell. A unique series of climatic events prevailed during much of the fire season — *the shell is loaded into the rifle chamber.* Smaller fires were burning in the forests and bogs — *the hammer is pulled back.* A favorable synoptic weather pattern developed over the region — *the trigger is pulled and the bullet is on its way.*

This study is primarily concerned with climatic events leading to great fires rather than with the analysis of the synoptic map features on the day of the fire. Therefore, this section will only touch on the important points of this last phase. Those interested in synoptic details may wish to read Beals (1914) for a discussion of pressure features that shows how they might have contributed to the high winds occurring with the 1881 and 1894 disasters. Richardson (1919) examined the 1918 Cloquet fire with the same objective in mind. Briefly, both authors concluded that the strong winds were fire-produced. For example, Richardson believes that during the Cloquet fire, synoptic features ". . . favored wind velocities not much in excess of 30-mile rates." Yet during the fire, Duluth registered maximum velocities of 65 m.p.h. and, according to Richardson winds were ". . . blowing at a rate of 80 to 90 miles adjoining the fire fronts from 2 to 6 miles or more distant from . . . (Duluth)."

Both Beal and Richardson were handicapped in their synoptic examinations by two factors. Frontal theory had not been developed at that time nor did the Weather Bureau take upper air soundings. Upper air patterns occurring during these events will never be known; however, a U.S. Air Force, Navy, and Weather Bureau team (1899-1955) has prepared a Historic Weather Map series and reanalyzed daily observations. This added information for 1918 shows that a frontal system passed over Minnesota on the 11th of October. By the morning of the 12th — the day of the fire — the cold front was well to the east, over eastern Michigan, with the 1,000-millibar, low-pressure system north of the Canadian border, near 90° W. longitude. A westerly flow pattern prevailed over Minnesota and Wisconsin, but the pressure gradient was not excessive. These added surface features help to substantiate Richardson's conclusion that large-scale pressure patterns did not cause the extremely high winds, but rather that ". . . the major force of the gale . . . was fire created."

Synoptic information is available through other sources describing the fires occurring after 1880; however, no good information is available for the 1871 fires. This was an especially interesting year because it saw the largest fire problem ever known triggered by an early October synoptic system. The Peshtigo, Chicago, and Lower Michigan fires resulted from it. Consequently, we will present the weather map features for this period.

A week of October 1871 weather observations were plotted on standard charts and analyzed. The analysis showed that a low-moisture, high-pressure cell moved through the Midwest on Thursday the 5th and Friday the 6th. By Saturday morning the northern sector of the double-celled 1,024-millibar high was centered over Ohio. The potential fire region was in the northwest quadrant of this high and coming under the influence of a complex low then over Montana and Wyoming.

As the first Chicago fire began late Saturday evening, this low had dropped southeastward and was causing a south-to-westerly flow pattern eastward to Lake Michigan. Winds were still relatively light at this time, with the highest in northern Illinois and Lower Michigan, 12 to 14 m.p.h. By Sunday morning this deepening low dominated weather over much of the Western Plains, and, in conjunction with the slow-moving high (1,032 millibars) centered over Virginia and North Carolina, it created an increased pressure gradient.

By Sunday afternoon a frontal system extending from a wave lay over central Minnesota (fig. 7), over northern Wisconsin, and continued into another low positioned east of lower Hudson Bay. Low-level, dry air was moving northeastward into the fire region, and high winds developed from Kansas through Michigan. At 2:00 p.m. EST Sunday, October 8, Milwaukee reported 32, Chicago 22, and Grand Rapids 23 m.p.h. The same conditions continued that evening, with the Peshtigo fire well underway and the Great Chicago fire just beginning, as south to southwest winds of 25 m.p.h. were blowing along both sides of Lake Michigan.

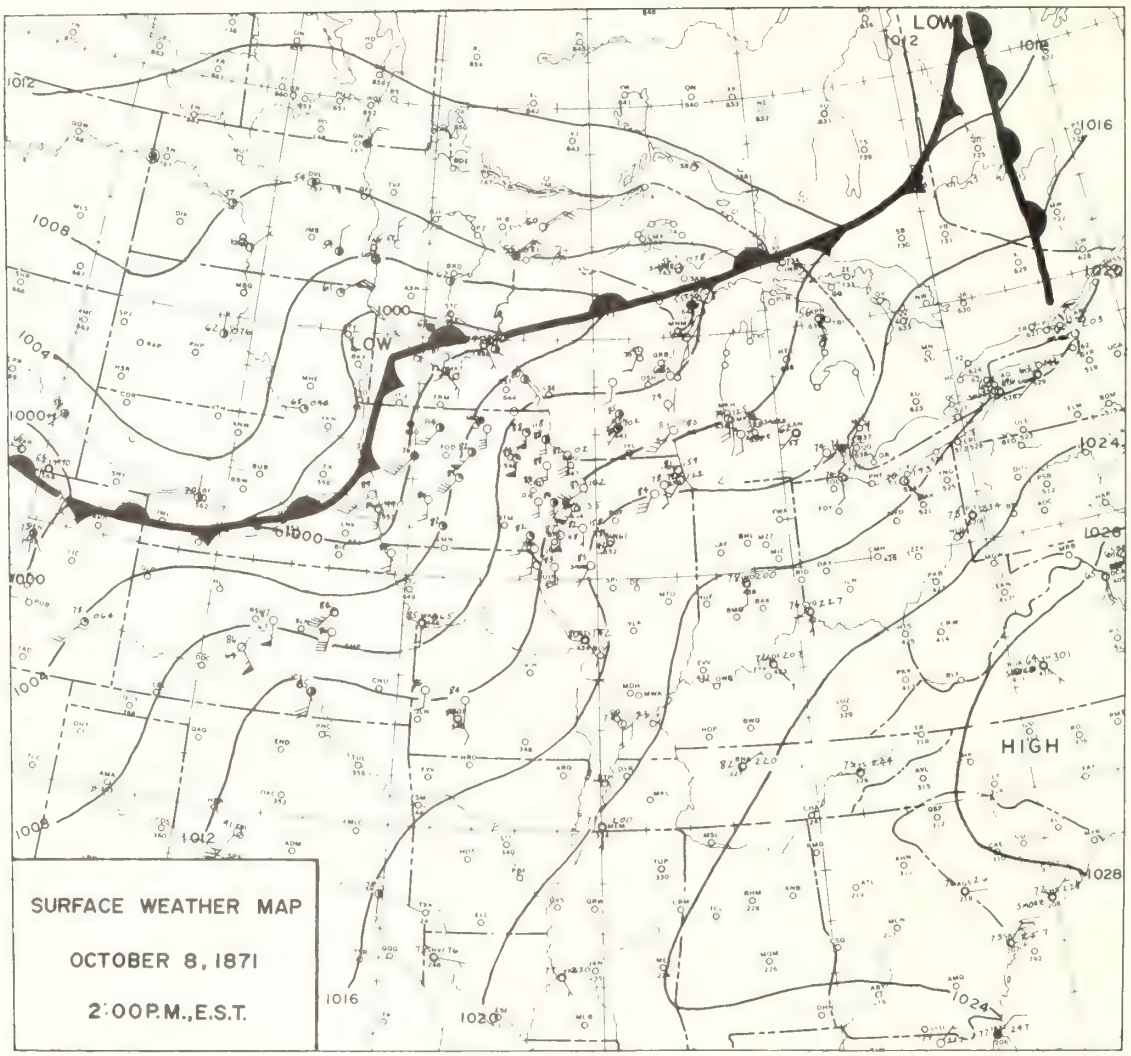

FIGURE 7. — Surface weather map at the time of the Chicago, Michigan, and Peshtigo fires, October 8, 1871, 2:00 p.m. EST. Isolines are drawn for 4-millibar intervals. Open station circles indicate mostly clear skies; half-filled circles represent partly cloudy skies; and filled circles, cloudy skies. Wind barbs conform to the Daily Weather Map code. Note the strong isotach field centered in Iowa, southeast Wisconsin, and northern Illinois.

Monday morning, October 9, the low had moved to southwestern Minnesota and winds of 14 to 16 m.p.h. prevailed in northeast Wisconsin and Lower Michigan. That evening the low was centered over northern Wisconsin. Winds of 20 to 26 m.p.h. were still reported in portions of the fire region.

By Tuesday morning, the 10th, the low was centered over the northern Great Lakes and by evening the associated cold front was pushing through extreme eastern Michigan. At 7:00 a.m. the Thunder Bay observer reported southerly winds of 25 m.p.h. and ". . . smoke so dense and heavy from the fires in the woods on the mainland . . . that the house had to be lighted up the same as night. Could not see to read any newspapers . . . the chickens went to their roosts, a most dismal sight. . . . At noon a heavy blast of wind from the SW continued all the rest of the day." Average winds of 45 m.p.h. were reported before and after the cold front passed over this island station.

Fire-day weather. — Weather conditions during the early afternoon on the day of each fire are tabulated in table 8. In addition, the National Fire Danger Rating Indexes (Nelson 1964) have been computed by using this data and are included in the table. These indexes are widely used in present-day fire-control operations as predictors of potential fire activity.

Table 8. — Weather conditions on the day of the fire [1]

Fire location	Weather station	Temperature	Relative humidity	Wind	National Fire Danger Rating		
					Buildup Index	Timber Spread Index	Fine Fuel Spread Index
		°F.	Percent	M.p.h.			
Peshtigo, Wis.	Sturgeon Bay	63	--	12	--	--	--
	Madison	80	24	12	101	51	57
	Embarrass	75	--	12	--	--	--
	Milwaukee	83	28	32	90	99	100
Chicago, Ill.	Chicago	85	24	22	80	74	87
Lower Michigan	Lansing (Oct. 9)	78	37	12	60	40	51
	Thunder Bay (Oct. 10)	57	--	45	--	--	--
	Grand Rapids (Oct. 9)	75	--	25	--	--	--
Michigan Thumb	Thornville (Aug. 31)	99	40	34	80	93	100
	Port Huron (Aug. 31)	94	--	2/ 25	--	79	94
Hinckley, Minn.	Sandy Lake	90	--	3/ 20	198	84	87
	Cambridge	94	--	3/ 20	74	74	87
	Collegeville	95	28	3/ 20	87	69	82
Baudette, Minn.	Duluth	70	34	4/ 22	51	60	74
	Roseau	76	--	--	51	--	--
Cloquet, Minn.	Cloquet	75	--	--	66	86	100
	Duluth	76	31	5/ 65	63	86	100

1/The 1871 temperatures were taken at 2:00 p.m. EST. All others are maximum temperatures. Unless noted, all relative humidity and wind velocity values were recorded during the early afternoon.

2/Beals (1914).

3/Maximum value recorded at St. Paul.

4/Maximum value observed for date.

5/Maximum wind for the day, but believed to be extremely strong because of the proximity of the large fire.

SUMMARY AND CONCLUSIONS

The most striking factor in the climatic conditions preceding these seven historic fires in the north-central region is the decreased precipitation over a 3- to 8-month period. In four cases, at least one weather station in the area recorded the lowest precipitation total ever observed. In another case it was the second lowest of record. Precipitation amount was a consistently good climatic indicator; precipitation frequency, on the other hand, varied from fire to fire and provided little additional information.

The data indicate that abnormally hot weather for the season is not a prerequisite to large fires in the north-central region. Although records show above-normal temperatures at some time during the fire year in all instances, most of the departures occurred early in the year. If we restrict temperature analysis to just the prolonged season of dry weather, then only the Hinckley disaster can be truly classed as hot and dry. Four fires actually had below-normal temperatures during the dry period. If we consider maximum temperature departure, again only 1894 recorded well-above-normal temperatures. Examining the frequency of hot days during the season also gave little additional information on temperature.

Short-term temperature fluctuations, however, do appear to be highly significant. Some weather stations recorded normal or even below-normal temperatures on a seasonal basis, but well-above-normal temperatures during the 10 days before the fire.

When we combine temperature and precipitation and use them to analyze agricultural drought, we find that vegetation was below wilt stage for from 1⅓ to 2½ months preceding the conflagrations. These conditions contributed to the serious fire problem by increasing the amount of available fuel.

Solar radiation, as revealed in the percentage of possible sunshine records, was generally above normal during spring and summer of the fire years. This, of course, substantiates our contention that drought was severe.

Lowered relative humidity in most cases also appears to have contributed to the drought conditions. The Michigan data of both 1871 and 1881 show near- or above-normal humidity during the prefire seasons, but all other fire years had below- to well-below-normal relative humidity for most of the season or the month preceding the fire. The Hinckley fire was preceded by the most extreme climatic conditions of any of the cases studied.

Over the past 50 years many of the once-burned forests have been regenerated and protected from fire. Moreover, residue from logging, thinning, and pruning in many of these forests provides an ample source of fuel for conflagrations. Arnold (1968), for example, believes that the Michigan forests today "provide a ready source of large amounts of fuel," and therefore Michigan has the basic ingredient needed for mass fires.

There is no reason why the unusual climatic conditions could not recur in the future; i.e., (1) below-normal precipitation for 3 to 8 months, (2) low vegetation in drought or wilting stage for 1⅓ to 2½ months, (3) long-term below-normal humidity, (4) above-average sunshine duration. In addition, the daily weather patterns that preceded these fires were not unique.

Present ignition potential is much more difficult to assess. All the fires studied burned extremely large areas in short periods of time. Today's large fires that commonly originate from one ignition point never approach the size of these historic fires. As examples, the 1967 Sundance fire of Idaho burned more than 50,000 acres (Anderson 1968), Montana's Sleeping Child fire of 1961 burned 33,000 acres, and Maine's Centerville fire of 1966 burned 12,000 acres. The major source of ignition — people — is greater than it was 50 years ago. However, public awareness of the importance of fire prevention and constant fire control efforts by State and Federal agencies have dampened the threat of major conflagrations. But until man learns how to fireproof the forest or modify the weather, he must remain constantly alert to the threat of new fire disasters, and continue to intensify forest fire prevention and control activities.

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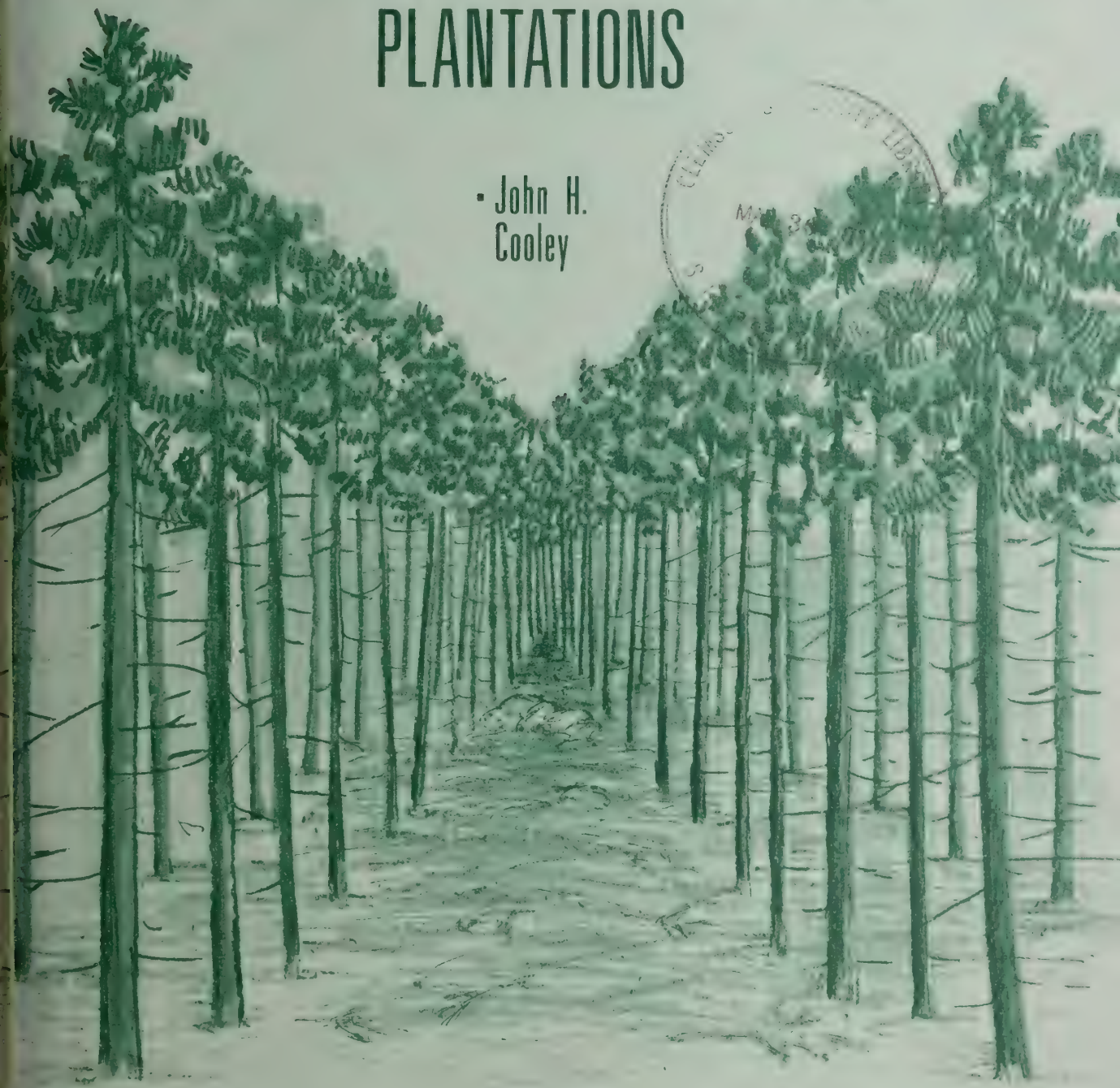
RCH PAPER NC-35

INITIAL THINNING IN RED PINE PLANTATIONS

• John H. Cooley



North Central Forest Experiment Station
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U.S. Department of Agriculture

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Initial Thinning in Red Pine Plantations

John H. Cooley

Michigan, Minnesota, and Wisconsin have approximately ¾ million acres of red pine plantations in which the trees are now, or soon will be, large enough to produce pulpwood. Thinning these plantations without delay can increase financial return and reduce the risk of insect and disease damage associated with intense, prolonged competition. The return that will be derived, however, will depend to a large extent on selecting the method and intensity of thinning best suited to each management situation. Fortunately, many thinning studies have been conducted in both natural and planted stands, and the economic implications of many alternatives have been compared. The purpose of this paper is to point out the consequences of certain thinning alternatives and to develop a prescription for initial thinning that will have wide application in the Lake States.

A primary objective of thinning studies has been to determine optimum stocking level, but most have shown that basal area growth varies little over a wide range of residual stand density (Buckman 1962a, b). Similarly, basal area growth seems to vary little over a broad range of thinning methods. Buckman (1962a) and Buckman and Wambach (1966) found no consistent differences among thinnings from above, below, and a combination of above and below. Day and Rudolph (1966) found that basal area growth in the first 3 years after thinning was at least as great where entire rows were removed as where individual trees were selected. In contrast, both residual stand density and cutting method have a major influence on tree diameter. The average stand diameter can be increased by cutting mostly smaller trees (thinning from below), or decreased by cutting mostly larger trees (thinning from above), and diameter growth rate can be stimulated by reducing stand density. Thus rotation length for trees of any given size will vary with density and cutting method even though total yield will not.

The economic implications of stand density have been worked out by Lundgren (1965) on the basis of growth and yield estimates for natural red pine stands in Minnesota (Buckman 1962a). He found the highest expectation value for red pine land to be associated with the lowest density included in his analysis — 90 square feet of basal area per acre. Apparently, differences in diameter growth rate have more effect on value yield than differences in cubic foot volume, even when there is no price differential associated with size. When large trees are worth more than small ones, differences in growth rate become more important. Buckman and Wambach (1966) found that thinning from below yielded a better return than thinning from above; again, this can be attributed to differences in the rate at which diameter increased.

Testing a variety of thinning methods and intensities in plantations at different locations in Lower Michigan generally corroborated findings of previous growth studies. Basal area growth was found to be nearly the same for a broad range of treatments, including: (1) removal of every other row, (2) removal of every third row, (3) selective thinning from above leaving densities ranging from 60 to 120 square feet of basal area per acre, (4) crown release of selected trees leaving the same range of densities, and (5) selective thinning from below leaving 60 square feet of basal area per acre or more.

Thinnings that reduced density to 40 square feet of basal area per acre or less usually reduced basal area growth. Diameter

growth was closely related to stand density, but did not seem to be influenced to any extent by thinning method, although the immediate effect on average stand diameter varied with the thinning method.

Study Description

Thinning plots were established in six plantations in Lower Michigan (table 1); plots in Plantations 1 and 2 constituted replicated studies. In both plantations, treatments included thinnings from below leaving 30, 60, 90, 120, and 150 square feet of basal area per acre, removal of every other row, and removal of every third row. In Plantation 1 treatments were replicated four times and in Plantation 2 they were replicated three times. In addition, thinnings from above to 60, 90, and 120 square feet, and crown thinnings to the same densities were tried in Plantation 2. Crown thinning was much the same as thinning from above and below to release the crowns of selected trees. One 5-year growth period has elapsed since these plots were first thinned.

In the other four plantations, compartments were thinned from below to 60, 80, 100, and 120 square feet of basal area per acre and each compartment was sampled with systematically located plots. These could not be treated as replications because of differences in age, site quality, and initial stand density, so they were compared subjectively. Three 5-year growth periods have elapsed since these plots were first thinned and compartments have been thinned to the prescribed basal area at the beginning of each period.

During this 15-year period a number of other thinning methods were tried in Plantation 4. One compartment was initially thinned by removing every other row and another by removing every third row. These row thinnings were made at the same time as the selective thinnings, but the row-thinned compartments were left for 10 years, and then thinned from below to leave 100 square feet of basal area per acre. Five years after the first selective thinnings, one compartment was thinned from below to 160 square feet, another was thinned leaving only intermediate and suppressed trees, and two others were thinned to 140 and 120 square feet leaving trees with the best potential for utility poles. Five years after this, one more compartment was thinned from below leaving 40 square feet of basal area per acre.

Table 1. — Characteristics of plantation in which thinning plots were established

Plantation	Age	Site index	No. of trees/acre	Basal area	Mean d.b.h.
	Years			Square feet/acre	Inches
1	19*	70	1,200	150	4.8
2	22*	68	1,080	135	4.8
3	24	66	720	130	5.7
4	39	49	1,500	205	5.0
5	34	48	810	115	5.1
6	34	39	760	100	5.0

* Replicated studies were established in these stands only.

Results

Because Plantations 1 and 2 had the greatest diversity of thinning treatments and the treatments were replicated, the data obtained from them provide a frame of reference for evaluating results at other locations (table 2). Variance analysis of basal

Table 2. — Basal area growth after thinning in Plantations 1 and 2
(In square feet of basal area per acre)

Thinning method	Prescribed residual density	Plantation 1		Plantation 2	
		Residual density	Periodic growth	Residual density	Periodic growth
Unthinned	---	150.6	33.0	136.6	34.4
Thinned from below	150	145.2	32.6	134.5	35.9
Thinned from below	120	118.8	30.6	119.8	33.8
Thinned from below	90	85.7	33.3	89.3	36.1
Thinned from below	60	58.2	33.4	61.2	35.4
Thinned from below	30	29.5	20.4	29.4	25.7
Thinned from above	120	*	*	116.7	32.4
Thinned from above	90	*	*	88.4	37.3
Thinned from above	60	*	*	58.9	37.6
Crown Release	120	*	*	119.7	34.5
Crown Release	90	*	*	87.6	34.5
Crown Release	60	*	*	60.9	34.2
Remove every other row	---	72.2	31.1	66.6	34.1
Remove every third row	---	104.6	34.1	91.1	39.2

* No thinning from above or crown release in Plantation 1.

area growth showed significant differences among treatment means for each of the two plantations. According to Duncan's multiple range tests, reduced growth on plots thinned to 30 square feet of basal area per acre accounted for the difference in both cases. Comparing the three selective thinnings in Plantation 2 indicated no differences due to cutting method and no interaction between residual basal area and cutting method. Basal area growth on row-thinned plots was not significantly different from that on plots thinned selectively to residual densities between 60 and 90 square feet per acre. However, all treatments that were tried in both plantations resulted in less growth in Plantation 1 than in Plantation 2, even though age and site index were nearly the same. This difference was significant at the 95 percent level.

Increases in mean stand d.b.h. were inversely related to residual basal area up to about 120 square feet (figs. 1 and 2). Check plots and those maintained at 150 square feet of basal area, from which only a few trees were cut, had about the same rate of diameter increase as those thinned to 120 square feet. On the average, these lightest thinnings had little effect on diameter growth. Each 10-foot reduction in basal area below 120 square feet per acre increased 5-year diameter growth by .119 inches in Plantation 1 and .140 inches in Plantation 2 whether trees were removed selectively or systematically.

Even though mean stand diameter growth was largely independent of cutting method, some methods immediately changed mean stand diameter. Thinning from below increased mean stand diamter by 1.5, 0.9, 1.2, and 0.4 inches d.b.h. in plots thinned to 30, 60, 90, and 120 square feet of basal area, respectively. Row thinning and crown thinning had almost no immediate effect, and

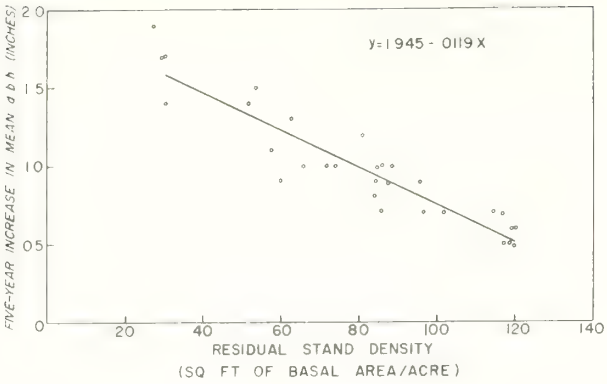

FIGURE 1. — Average 5-year d.b.h. increase in Plantation 1 on all plots thinned to between 30 and 120 square feet of basal area per acre.

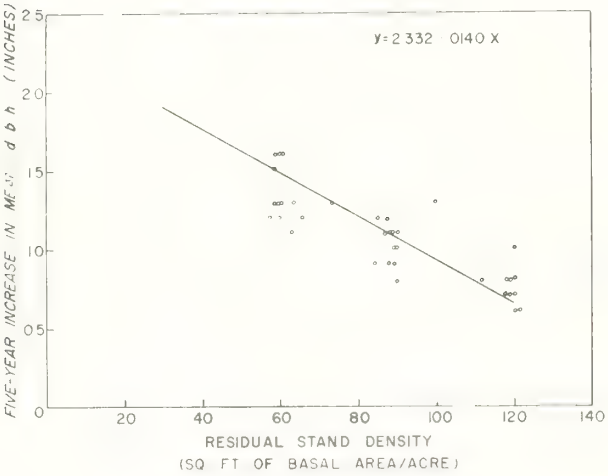

FIGURE 2. — Average 5-year d.b.h. increase in Plantation 2 on all plots thinned to between 30 and 120 square feet of the basal area per acre.

thinning from above decreased mean stand diameter by 0.6, 0.3, and 0.0 inches d.b.h. in stands thinned to 60, 90, and 120 square feet of basal area, respectively.

Basal area growth at each density level varied widely in the other four plantations, but these variations generally did not contradict the relationships observed in Plantations 1 and 2. The one plot in Plantation 4 that was thinned to less than 60 square feet of basal area per acre grew much less than any of the others in that plantation. In all plantations, plots thinned to between 60 and 120 square feet of basal area grew best during the first and second growth periods. During the third period unthinned plots made the best growth in Plantations 3 and 4; otherwise those thinned to between 60 and 120 square feet grew best during this period also. Most of the special thinnings in Plantation 4, including both row thinnings, resulted in as much growth as thinning from below. The only exceptions were the first thinning to release intermediate and suppressed trees, and the first pole thinning leaving 140 square feet of basal area.

Diameter growth trends in the other four plantations were generally consistent with those in Plantations 1 and 2. Thinning from below to the higher residual densities elicited little response, if any, because only a few intermediate and suppressed trees were cut (table 3). But in Plantation 4, where the initial density was over 200 square feet per acre, thinning to 140 square feet did increase growth. In other words, if the thinning removed enough basal area to increase growing space for residual trees, there was a strong and consistent relationship between diameter growth and residual density.

In Plantation 4 this relationship was evident for other methods as well as for thinning from below. On row-thinned plots, which averaged 99 square feet of basal area per acre after their first thinning and were thinned selectively to 100 square feet 10 years later, 15-year d.b.h. increase was about 2.6 inches. During the same period on plots thinned selectively every 5 years to 100 square feet, d.b.h. increase was 2.4 inches. Pole thinnings to 120 square feet resulted in a mean 5-year d.b.h. increase of 0.6 inches. Thinning from above left a stand of 120 square feet after the first thinning, and the mean d.b.h. increase was 0.4 inches during the next 5 years. The second thinning from above left a residual stand of 116 square feet, and ensuing 5-year d.b.h. increase was 0.9 inches. So the 10-year increase on this plot was about 1.3 inches, which was comparable to plots thinned selectively to 120 or 140 square feet.

As in Plantations 1 and 2, site index was weakly related to growth. In Plantation 4,

Table 3. — Five-year increase in mean stand d.b.h. after thinning from below and in unthinned plots in Plantations 3, 4, 5, and 6
(In inches d.b.h.)

Plantation	Prescribed residual density (sq. ft. of basal area/acre)							Unthinned plots
	40	60	80	100	120	140	160	
3	(1/)	1.3	0.8	0.7	0.7	0.5	(1/)	0.4
4	2/1.7	1.4	1.0	0.8	0.6	0.6	0.3	0.3
5	(1/)	1.0	0.8	0.5	0.4	0.4	(1/)	0.4
6	(1/)	0.7	0.6	3/0.5	2/0.3	2/0.4	(1/)	0.4

1/ No plots thinned to this density.
2/ Growth during third period.
3/ Average growth during second and third periods.

which had a site index of 49, the average 5-year growth on all plots thinned to between 60 and 120 square feet of basal area per acre was 28 square feet, but in Plantation 3, which had a site index of 66, it was only 24 square feet. Furthermore, Plantation 3 was younger when it was thinned for the first time, and thus might have been expected to respond better. After the second and third thinnings to the same range of densities, average 5-year growth in Plantation 5 was 10 square feet less than in Plantation 4, even though their site indexes were nearly the same. In Plantation 6 growth averaged only 2 square feet less than in Plantation 5, although its site index was nine units lower.

Discussion

Although some of the comparisons given here are subjective, they suggest that basal area growth after thinning in a red pine plantation depends largely on factors that cannot be controlled by the forester. Residual basal area has a marked effect on basal area growth only when it is so low that there are not enough trees to fully utilize the site, or when it is so high that trees are lost to mortality. In young red pine plantations, 60 square feet of basal area per acre apparently represents the lowest stocking that will fully utilize most sites. If it is assumed that above this level of stocking basal area growth is the same, higher densities will yield more volume growth. However, diameter growth will be faster at lower densities, and economic analyses based on growth in natural stands (Lundgren 1965) suggest that differences in diameter growth influence value return more than differences in volume growth as long as the site is fully stocked. Therefore, many owners would find densities of about 60 square feet of basal area per acre most profitable.

The method of selecting trees to cut does not appear to influence either basal area or diameter growth. Apparently, red pine in plantations is so uniform that growth is about the same no matter which trees are removed, as long as the residual trees are reasonably well distributed. However, thinning from above will reduce average stand diameter at the time of thinning, thus lengthening the rotation. Thinning from below has the opposite effect, whereas crown thinning has little immediate effect on average stand diameter.

Systematic removal of rows also has little immediate effect on average stand diameter, and mean stand diameter growth is as rapid after this kind of thinning as it is after selective removal of individual trees. It follows that dominant and codominant trees must grow at the same rate in plantations that are row-thinned as in those that are thinned selectively from below. Therefore, if rows were removed systematically in the initial thinning and subsequent thinnings were from below,

rotations should be as short as if the first thinning were from below. Row thinning requires a minimum of marking and reduces logging costs by concentrating material in access trails. These access trails also facilitate future logging operations. For the first thinning, then, most owners will find removal of complete rows desirable.

Obviously, a strictly mechanical row thinning will not leave a uniform stand of 60 square feet per acre, but this can be modified by varying the number of rows cut or by thinning from below in rows that are not removed completely. Where trees were not planted in regular, parallel rows, row thinning, as such, will not be feasible, but some of the advantages can be realized if all trees are removed from closely spaced trails to provide access and the remaining stand is thinned from below leaving about 60 square feet of basal area per acre.

Summary

A variety of thinning methods and intensities were tested in red pine plantations in Lower Michigan. Replicated studies in two plantations showed that neither residual density nor method of selecting trees for removal influenced subsequent basal area growth, except where plots were thinned to 30 square feet per acre. This was confirmed by observations in four additional plantations. Thinning from below increased mean stand diameter, thinning from above decreased it and these changes were roughly proportional to reduction in stand density. Diameter growth was shown to be strongly influenced by residual density if enough basal area was removed to increase growing space for residual trees.

It was concluded that thinning to about 60 square feet would be most profitable to most owners because it shortens the rotation as much as possible without seriously reducing volume yield. It was further concluded that row thinnings minimize costs and facilitate both current and future logging operations. To leave approximately 60 square feet of basal area per acre, it is necessary to vary the number of rows cut and cut selectively in uncut rows. Where trees were not planted in parallel rows, the stand can be reduced to 60 square feet of basal area per acre by removing enough trees to create closely spaced access trails, and by thinning the rest of the stand from below.

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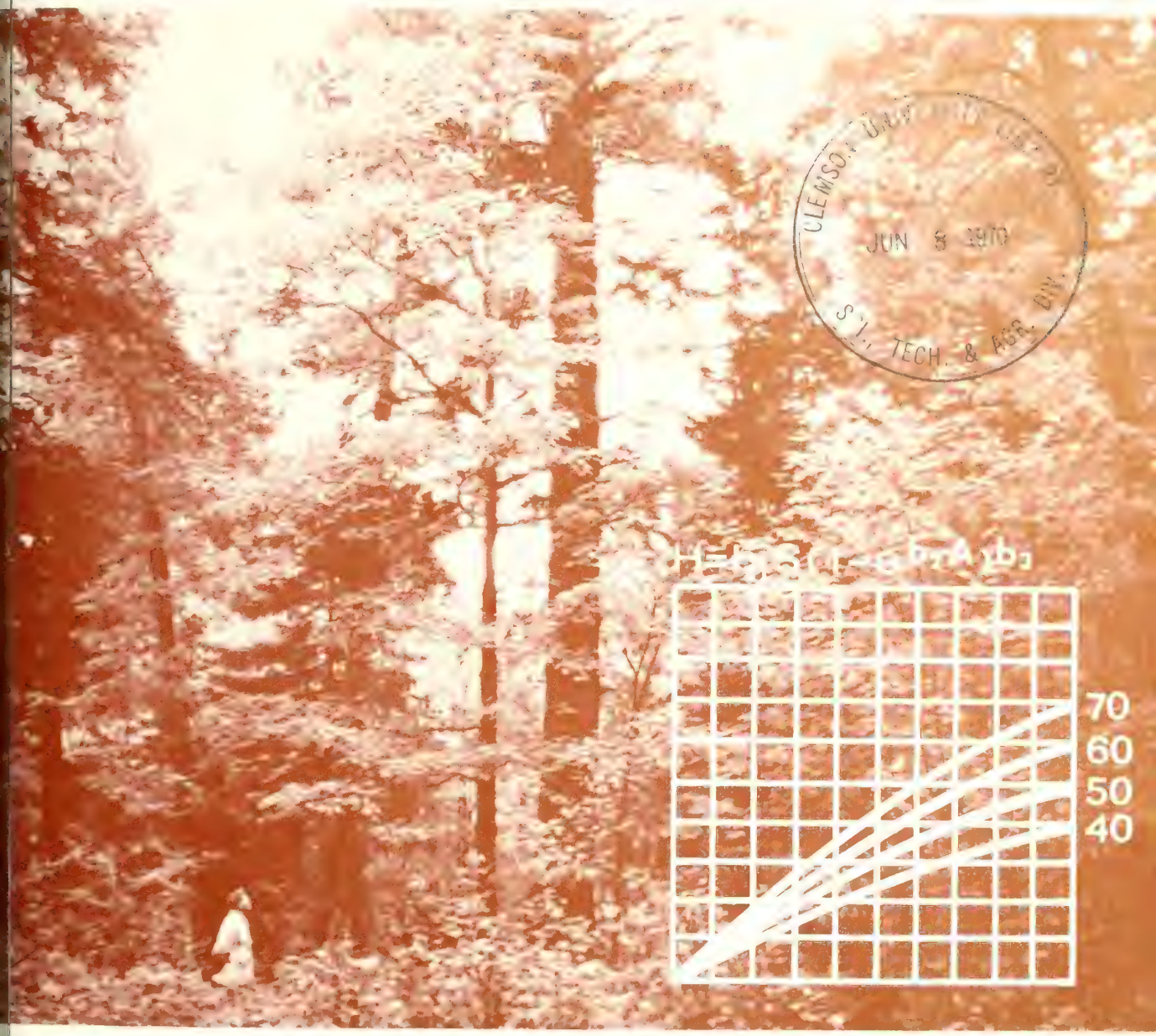

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Biological growth functions describe published site index curves for Lake States timber species

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BIOLOGICAL GROWTH FUNCTIONS DESCRIBE PUBLISHED SITE INDEX CURVES FOR LAKE STATES TIMBER SPECIES

"Is it of trees you tell, their months and virtues . . . ?" [1]

Published site index curves for Lake States timber species are widely used to identify potential site productivity based on the height and age of existing trees. In the absence of height-growth functions, they are also used to estimate height-growth of trees and stands. For example, Buckman (1962) and Lundgren (1965) used site index curves by Gevorkiantz (1957e) to estimate height-growth of red pine, assuming that the average tree in a stand would follow the heights traced by the site index curves at various ages.

Both uses require reading values from curves on a graph, and interpolating between lines for those ages, heights, and site indexes not specifically shown. Such readings are tedious and subject to human error, particularly when many readings must be made. Further, repeat readings for the same points may be inconsistent because of the human judgment necessary in interpolation.

To overcome these difficulties and to facilitate using this information in computers, two types of biological growth functions representing height as a function of age and site index have been fitted to 11 published site index curves available for Lake States timber species. In developing these functions, the goal was to closely reproduce existing curves by a convenient mathematical expression. The object was not to replace existing site index curves, but to supplement them with a mathematical function and a convenient table of height factors.

Several mathematical functions have been used to represent site index curves (Stage 1963). Because the available data of height over age are related to growth (although in a somewhat contrived way), biological growth functions appear more appropriate than, say, polynomials. We chose to use two versions of a biological growth function, the monomolecular curve (Richards 1959), to represent height as a function of site index and age.

THE EXPONENTIAL-MONOMOLECULAR FUNCTION

The first and more complex form of the monomolecular function we call the exponential-monomolecular function. The equation form considered was:

$$H = b_1 \ S\left(1-e^{b_2 A}\right)^{b_3}$$

where H = Total height of tree in feet

S = Site index (height at age 50 years)

A = Age in years

and b_1, b_2, b_3 are parameters to be estimated

e = base of the natural logarithms

[1] *From TO JUAN AT THE WINTER SOLSTICE by Robert Graves, by permission of Collins-Knowlton-Wing, Inc. Copyright© November 1945 by Robert Graves.*

The choice of this function was a compromise between simplicity of calculation, both in obtaining the parameters and using the function to estimate heights, and accuracy of fit over a wide range of tree ages. It is similar to the average height-age function used by Brickell (1968). This function has the desirable S-shape with a height of zero at age zero. It specifies that the height at any given age is proportional to site index. It does not specify that the height at age 50 must exactly equal the site index, but the error in predicted height at age 50 never exceeds 0.6 feet for the species considered here. When b_2 is negative and b_3 is positive, as they are here, then as age increases height approaches an upper limit of $b_1 S$.

The parameters b_1, b_2, and b_3 were estimated for each species by least squares techniques using a modified form of TARSIER, a nonlinear regression program (Atkinson 1966). The equation was fitted to heights read to the nearest foot from the published site index curves for each species over the range of ages and sites given. Thirty to 60 readings were made for each species.

The data source, range of ages, and range of site indexes for each species considered are given in table 1. For each species the values of the three estimated parameters b_1, b_2, and b_3, the R^2 value, the standard error, and the maximum error of individual observations were obtained by fitting the equation to the observed readings (table 2). Keep in mind that these apply only to the readings made from the curves and not to the data underlying the curves.

As an example, the height equation for red pine is:

$$H = 1.890\, S\left(1-e^{-.01979A}\right)^{1.3892}$$

For a site index of 60, the height at age 30 would be:

$$H = 1.890\,(60)\left(1-e^{-.01979\,(30)}\right)^{1.3892}$$

$$= 113.4\left(1-e^{-.5937}\right)^{1.3892}$$

$$= 37.14 \text{ feet}$$

Rounded to the nearest foot, this is exactly the reading of 37 feet obtained from the published site index curves.

The annual height growth (ΔH) at any age on a given site can be closely estimated by the first partial derivative of the height equation with respect to age.

$$\Delta H \simeq \frac{\partial H}{\partial A} = b_1\, b_2\, b_3\left(-e^{b_2 A}\right)\left(1-e^{b_2 A}\right)^{b_3-1} S$$

This equation predicts annual height growth for a given age and site. By substituting in the original equation for height, this height-growth equation can be reduced to a function of height and age:

$$\Delta H \simeq -b_2\, b_3\left(e^{-b_2 A}-1\right)^{-1} H$$

For red pine, the annual height growth estimated by this last equation would be:

$$\Delta H \simeq 0.027492\left(e^{.01979A}-1\right)^{-1} H$$

At age 30 the annual height growth of red pine would be:

$$\Delta H \simeq .034\, H$$

We have already seen that the height of a red pine tree at age 30

Table 1. — *Species, data source, and range of ages and site indexes used in developing site index functions*

Species	Data source	Range of ages	Range of site index
		Years	
Red pine (*Pinus resinosa*)	Gevorkiantz (1957e)	20-120	40-70
Jack pine (*Pinus banksiana*)	Gevorkiantz (1956a)	20-80	30-70
White pine (*Pinus strobus*)	Gevorkiantz (1957d)	20-120	40-80
Balsam fir (*Abies balsamea*)	Gevorkiantz (1956c)	1/ 20-80	30-70
White spruce (*Picea glauca*)	Gevorkiantz (1957c)	1/ 20-120	30-80
Black spruce (*Picea mariana*)	Gevorkiantz (1957b)	20-120	20-60
Tamarack (*Larix laricina*)	Gevorkiantz (1957g)	20-120	20-60
White-cedar (*Thuja occidentalis*)	Gevorkiantz (1957a)	20-100	20-60
Aspen (*Populus tremuloides*)	Gevorkiantz (1956b)	20-80	40-80
Red oak (*Quercus rubra*)	Gevorkiantz (1957f)	20-120	40-70
Paper birch (*Betula papyrifera*)	Cooley (1958)	20-80	40-80

1/ Breast-height age.

on site index 60 is 37 feet. Using this height in the above equation we find that the expected annual height growth of a dominant red pine on site index 60 at age 30 is 1.3 feet per year.

Note that site index (S) can be calculated directly from an observation of height ($H_{obs.}$) at some observed age ($A_{obs.}$) by rearranging the height equation:

$$S = H_{obs.}\ b_1^{-1}\ (1-e^{b_2 A_{obs.}})^{-b_3}$$

This can be substituted back into the original equation to estimate the height (H) at any age (A) from one observed height and age determination in a stand:

$$H = H_{obs.}\ (1-e^{b_2 A_{obs.}})^{-b_3}(1-e^{b_2 A})^{b_3}$$

The equations for all species except red oak and white spruce have a standard error of less than 1 foot. The maximum difference between observed and predicted heights for individual observations is less than 2 feet for all but these two species. Because it is difficult to read heights from these curves even to the nearest foot, maximum differences of less than 2 feet in using these functions to represent

Table 2. – *Parameters of the exponential-monomolecular function describing published site index curves* [1]

Species	Parameters			R^2	Standard error	Maximum error [2]
	b_1	b_2	b_3		Feet	Feet
Red pine	1.890	-0.01979	1.3892	0.9994	0.64	1.4
Jack pine	1.633	-.02233	1.2419	.9994	.50	1.1
White pine	1.966	-.02399	1.8942	.9996	.66	1.7
Balsam fir	1.437	-.02266	.9381	.9985	.69	1.9
White spruce [3]	1.637	-.02541	1.5403	.9784	3.98	9.4
Black spruce	1.762	-.02011	1.2307	.9990	.72	1.9
Tamarack	1.547	-.02246	1.1129	.9993	.52	1.4
White-cedar	1.973	-.01535	1.0895	.9990	.66	1.7
Aspen	1.480	-.02140	.9377	.9996	.41	1.1
Red oak	1.558	-.02179	1.0673	.9955	1.42	4.5
Paper birch	1.598	-.01938	.9824	.9998	.32	.6

1/ Height = b_1 (Site Index)$(1-e^{b_2(\text{Age})})^{b_3}$

2/ Maximum difference between observed and predicted heights over the range of data points analyzed (see table 1).

3/ This function is not recommended for white spruce.

the published site index curves should be acceptable. Most differences will be less than 1 foot.

The function for red oak can be used with confidence on all sites at ages below 90 years, and on sites from SI 50 to SI 65 at older ages. All differences between observed and predicted heights greater than 2 feet occurred only on the lowest and highest curves, and then only at ages of 90 years and older.

The ages given for balsam fir and white spruce are breast height ages; that is, the height for each of these two species at age zero is 4.5 feet. A revised function incorporating an added constant of 4.5 feet was fit to these two species. However, this revised function did not fit the balsam fir curves as well as did the original function and so was discarded. We recommend using the original function for balsam fir, but only for stands at least 20 years old.

The revised function did give a slightly better fit for the white spruce curves, but both functions gave unacceptably large errors for all but the site index 60 curve. Neither function can be recommended for the published white spruce site index curves.

A SIMPLER MONOMOLECULAR FUNCTION

Most of the published site index curves examined here show heights only for ages 20 and older, and show no point of inflection. Thus the simple monomolecular function, which has no point of inflection, also appears appropriate for representing

these published curves.

The initial equation form considered was:

$$H = S\,(a + b_1\, e^{b_2 A})$$

where H = height in feet

S = site index (height at 50 years)

A = age in years

and a, b_1, b_2, are parameters to be estimated.

This equation provides that the height at any given age is proportional to site index. When b_1 and b_2 are negative, as they are here, then as age increases, height approaches an upper limit of aS.

By definition, a necessary condition for any site index curve equation is that $H=S$ at the index age (50 years for all of the species considered here). To insure that $H=S$, the parameter a in the initial equation was replaced by the expression $(1\text{-}b_1 e^{b_2(50)})$. The revised form of the equation fitted to the data by regression analysis was:

$$H = S\,(1\text{-}b_1\, e^{b_2(50)} + b_1 e^{b_2 A})$$

The parameters b_1 and b_2 in this equation were estimated for each species by the same least squares techniques used to fit the exponential-monomolecular function.

After estimating b_1 and b_2 by regression analysis, the parameter a in the initial equation was computed from:

$$a = 1\text{-}b_1\, e^{b_2 50}$$

This value of a was then substituted back into the original equation, together with the values of b_1 and b_2 to provide the final equation used in expressing the relationship of height, site index, and age:

$$H = S(a + b_1\, e^{b_2 A})$$

For each species the values of a and the two estimated parameters b_1 and b_2, together with the R^2, the standard error, and the maximum error of individual observations were obtained by fitting the revised equation to the observed readings (table 3).

As an example, the height equation for red pine is:

$$H = S(1.956 - 2.1757e^{-.01644A})$$

For a site index of 60, the height at age 30 would be:

$$H = 60(1.956 - 2.1757e^{-.01644(30)})$$
$$= 60\,(0.62737)$$
$$= 37.6 \text{ feet}$$

This is close to the reading of 37 feet obtained from the published site index curve.

The annual height growth ($\triangle H$) at any age on a given site can be estimated by the first partial derivative of the height equation with respect to age:

$$\triangle H \simeq \frac{H}{A} - S(b_1\, b_2\, e^{b_2 A})$$

For red pine, the annual height growth would be:

$$\triangle H \simeq S(0.03577e^{-.01644A})$$

On a site index of 60, annual height growth at age 30 would be:

$$H \simeq 60(0.03577e^{-.01644(30)})$$
$$\simeq 60\,(.022) = 1.3 \text{ feet per year.}$$

Note that site index (S) can be calculated directly from an observation of height ($H_{obs.}$) at some ob-

Table 3. — *Parameters of a monomolecular growth function describing published site index curves* [1]

Species	Parameters			R^2	Standard error	Maximum error [2]
	a	b_1	b_2			
					Feet	Feet
Red pine	1.956	-2.1757	-0.01644	0.9994	0.67	1.4
Jack pine	1.677	-1.8063	-.01963	.9993	.57	1.2
White pine	2.174	-2.5616	-.01560	.9987	1.27	3.1
Balsam fir	1.419	-1.3938	-.02403	.9984	.74	1.9
White spruce [3]	1.662	-1.9864	-.02198	.9778	4.14	9.5
Black spruce	1.831	-1.9405	-.01696	.9988	.80	1.6
Tamarack	1.556	-1.6268	-.02149	.9993	.54	1.4
White-cedar	2.020	-2.0630	-.01409	.9989	.71	1.8
Aspen	1.460	-1.4337	-.02274	.9995	.45	1.1
Red oak	1.582	-1.6005	-.02023	.9953	1.50	4.6
Paper birch	1.594	-1.5841	-.01961	.9997	.35	.6

1/ Height = (Site Index)$(a + b_1 e^{b_2(\text{Age})})$

2/ Maximum difference between observed and predicted heights over the range of data points analyzed (see table 1).

3/ This function is not recommended for white spruce.

served age ($A_{obs.}$) by rearranging the height equation:

$$S = H_{obs} \left(a + b_1 e^{b_2 A_{obs}}\right)^{-1}$$

This can be substituted back into the original equation to estimate the height (H) at any age (A) from one observed height and age determination in a stand:

$$H = H_{obs} \left(a + b_1 e^{b_2 A_{obs}}\right)^{-1} \left(a + b_1 e^{b_2 A}\right)$$

All species except white pine, red oak, and white spruce had a standard error of less than 1 foot. The maximum difference between observed and predicted heights for individual observations was less than 2 feet for all but these three species. Thus, these equations should be acceptable for representing the published site index curves.

The function for white pine can be used with confidence to represent the published curves. Only one predicted height differed by more than 2.1 feet from the observed reading, and apparently this was due to an error in drafting the curve. Eighty percent of the observations differed by less than 1½ feet.

The function for red oak can be used with confidence on all sites at ages below 90 years, and on sites from SI 50-65 at older ages. All differences between observed and predicted heights greater than 2 feet occurred only on the lowest and highest site index curves, and then only at ages of 90 years and older.

Use of this monomolecular function for white spruce is not recommended.

HEIGHT FACTORS SIMPLIFY USE

Although convenient for computer use, the functions suggested here are not easy to evaluate by hand. To make these equations more useful, the following table of height factors is provided (table 4).

The height factors shown are nothing more than the height per unit of site index at specified ages. The height factor equation is:

$$H/S = b_1 \left(1 - e^{b_2 A}\right)^{b_3}$$

Multiplying the height factor at a given age by the site index gives the height of the tree in feet at this age. For example, a 70-year-old jack pine on site index 60 would be expected to have a height of 73.2 feet:

$$H = 1.22(60) = 73.2 \text{ feet}$$

The 10-year growth in height for any species can be estimated by taking the difference between factors for the two ages and multiplying by the site index. Thus, the height growth of red pine from age 30 to age 40 on site index 50 would be:

$$(.82 - .62)50 = (.20)50 = 10 \text{ feet}$$

These factors can be graphed and a curve fitted through the plotted points so that a factor can be read for every age. They also can be used to construct a set of site index curves for any desired site indexes.

For convenience, the tables show factors calculated for ages 10 to 150 years. The range of the data on which these factors are based is outlined in black. Any factors outside this range should be used only with caution, recognizing that they are extrapolations beyond the range of the data.

CONCLUDING REMARKS

Both the exponential-monomolecular and monomolecular functions closely fit the published site index curves for all Lake States species except those for white spruce. In general, the exponential-monomolecular model provides a slightly better overall fit. It passes through the origin, assuring a height of zero at age zero. Also, it is the more flexible function of the two, assuming an S-shape for values of b_3 greater than 1 but less than 2, and the simpler monomolecular shape for values of b_3 of 1 or less. Nevertheless, over the range of ages and sites used here the differences between functions are small. Either can be used with confidence to represent the published curves.

Both functions were fitted to heights only within the range of ages shown on the published site index curves. However, extrapolations beyond the oldest age shown on the published curves are consistent with general observations about height growth of older trees. With care such extrapolations may be used in the absence of better information.

Anyone using these functions should, of course, keep in mind the limitations of site index curves. A brief discussion of the use and limitations of site index will be found on the back page of every site index curve publication by Gevorkiantz.

Table 4. – *Height factors (F) by species and age for the exponential-monomolecular function;* [1] *Tree height = F x S, where S = Site index*
(In feet per unit of site index)

Age	Red pine	Jack pine	White pine	Balsam fir	Black spruce	Tamarack	White-cedar	Aspen	Red oak	Paper birch
Years										
10	0.17	0.22	0.11	0.32	0.22	0.26	0.24	0.32	0.27	0.29
20	.40	.46	.32	.56	.45	.50	.46	.55	.51	.52
30	.62	.67	.56	.74	.67	.70	.67	.73	.71	.71
40	.82	.85	.79	.88	.85	.86	.84	.88	.87	.87
50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	1.14	1.12	1.18	1.09	1.14	1.11	1.13	1.09	1.11	1.11
70	1.27	1.22	1.33	1.16	1.25	1.19	1.25	1.17	1.20	1.19
80	1.37	1.30	1.46	1.22	1.34	1.26	1.35	1.23	1.27	1.26
90	1.46	1.37	1.56	1.26	1.41	1.32	1.44	1.28	1.33	1.32
100	1.54	1.42	1.64	1.30	1.48	1.37	1.51	1.32	1.37	1.37
110	1.60	1.46	1.71	1.33	1.53	1.40	1.58	1.35	1.41	1.41
120	1.65	1.49	1.76	1.35	1.57	1.43	1.63	1.37	1.44	1.44
130	1.69	1.52	1.80	1.37	1.60	1.45	1.68	1.39	1.46	1.47
140	1.73	1.54	1.84	1.38	1.63	1.47	1.72	1.41	1.48	1.49
150	1.76	1.56	1.86	1.39	1.66	1.49	1.76	1.42	1.50	1.51

1/ Height in feet per unit of site index = $F = b_1 (1-e^{-b_2 A})^{b_3}$.
Range of data bounded by black line.

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defect indicators in Sugar-Maple

A PHOTOGRAPHIC GUIDE

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DEFECT INDICATORS IN SUGAR MAPLE – A PHOTOGRAPHIC GUIDE

Richard M. Marden and Charles L. Stayton

The hardwood tree or log grader has two fundamental tasks: first, he must determine the most valuable use for a tree or log, and second, he must predict the amount and value of the products that will be derived. His success in meeting these objectives will depend on the inherent accuracy of the grading system and on his skill in recognizing exterior defect indicators and correctly associating them with degrade to the interior of the tree. The significance of the exterior indicators and their associated interior defects varies with end products, but whatever the end product, a knowledge of this exterior-interior relationship is required.

To help the grader "see inside" the tree, we photographed the major exterior defect indicators on old-growth sugar maple trees in the Lake States. Then we cut open each tree and photographed the associated interior defects. Careful study of the related photographs, along with the accompanying descriptions, should help the new grader correlate what he can see with what he cannot see, and thus speed up his training. Beyond this immediate benefit, it is hoped also that these photos may facilitate the development of better log and tree grading systems in the future.

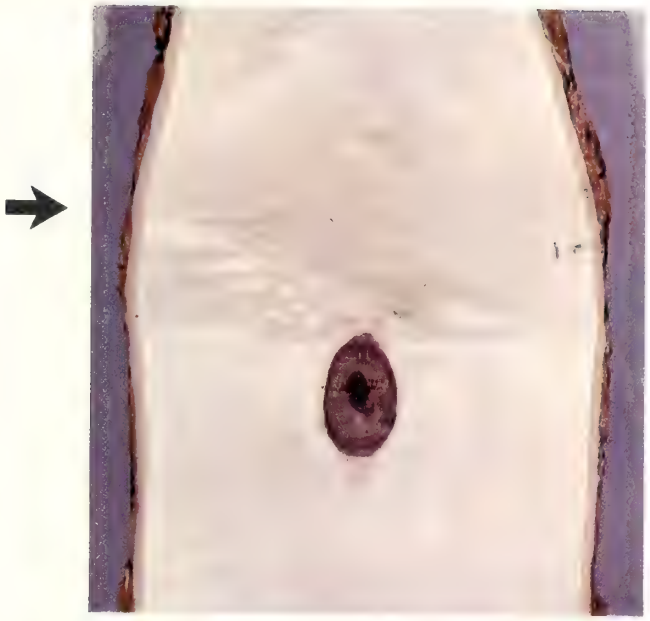
Only defects caused by "Natural" or mechanical phenomena are included; disease-caused defects, because of their diversity and complexity, are not treated here.

Unless otherwise indicated, photographs are approximately one-third actual size.

SOUND KNOT

F-519231

Live limbs are usually sound, or free from decay. In sugar maple, decay begins soon after a limb dies or breaks off. Sound primary limbs continue through the tree to the pith. If the branch is not broken and does not have damaged bark, it is usually sound. Arrows indicate the same point on corresponding exterior and interior photographs. All scales on photographs equal 1 inch.



Depth 3 inches[1] F-519232

Depth 4 inches F-519233

Depth 5 inches F-519234

[1]*Depth indicates radial distance inward from bark surface.*

UNSOUND KNOT

F-519235

F-519236

This indicator includes dead limbs or remnants of limbs. They may be protruding from, flush with, or depressed within the bark surface. The exposed wood shows evidence of decay. All primary limbs (sound and unsound) penetrate to the pith of the tree.

Depth 4 inches F-519237

Depth 7 inches F-519238

OVERGROWN KNOT

F-519239

This indicator is a limb stub that has been overgrown with wood, bark, and finally callus tissue. It may or may not protrude beyond the normal contour of the log or tree surface. The limb stub is eventually completely healed over, but it can be identified for many years by a definite circular design of swirls or lines that break up the normal bark pattern.

Depth 1 inch F-519240

Depth 2 inches F-519241

Depth 3 inches F-519242

BUMP

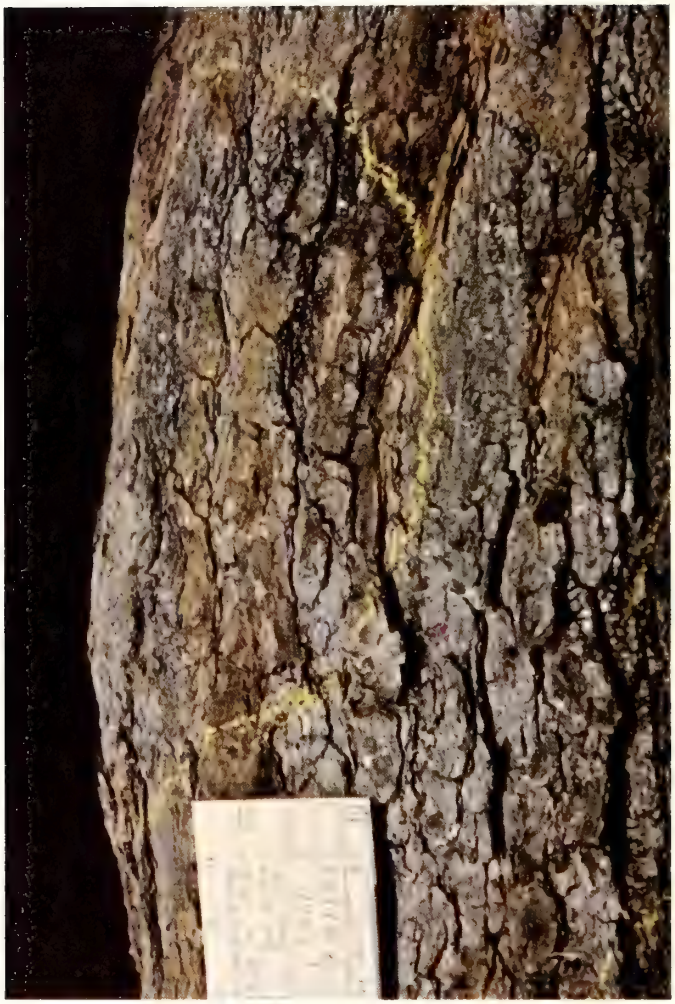
F-519243

A bump is a circular or elliptical protuberance overgrown with bark. It may be a gradual or abrupt swelling above the normal contours of the tree. The more abrupt bumps have a height-to-radius ratio of less than 1:3 (that is, the average distance from the center to the edge of the bump is less than three times the distance from the normal contour of the tree surface to the outermost extension of the bump). The more gradual bumps have a height-to-radius ratio of less than 1:6 and may gradually taper back in all directions to the normal surface of the log or tree. If the taper ratio is greater than 1:6, the defect indicator is classified as a surface rise.

Depth 3 inches F-519244

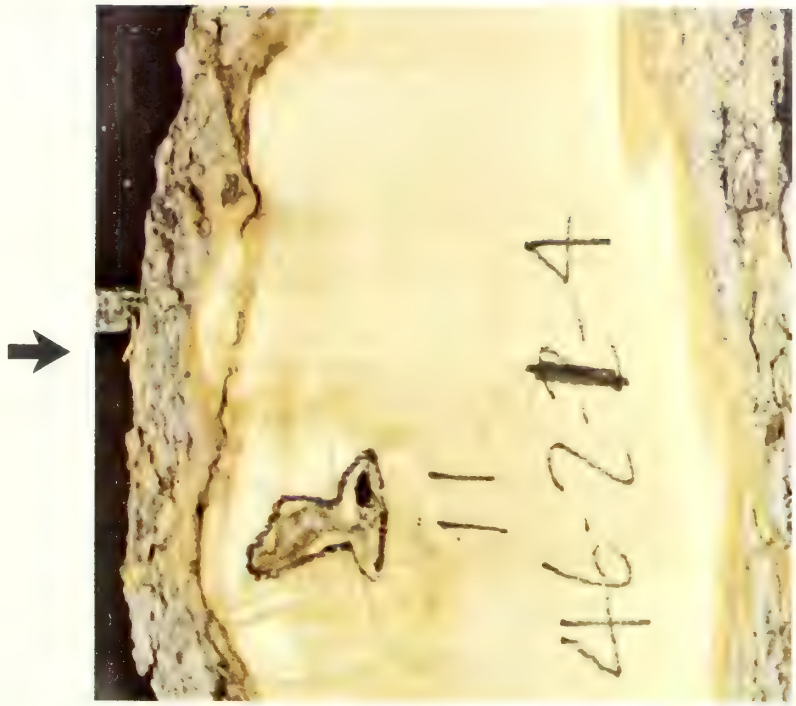
Depth 5 inches F-519245

SURFACE RISE



F-519246

A surface rise appears nearly identical to a bump except that its height-to-radius ratio is more than 1:6. Therefore, the surface rise is usually more elliptical than circular in shape. The swelling gradually tapers back to the normal contour of the log or tree surface.



Depth 1 inch F-519247

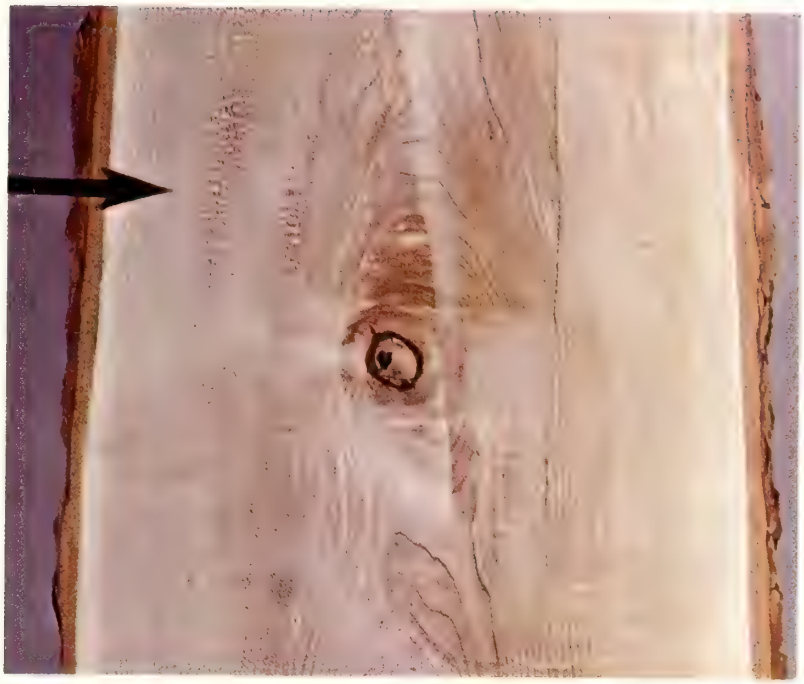
Depth 2 inches F-519248

Depth 3 inches F-519249

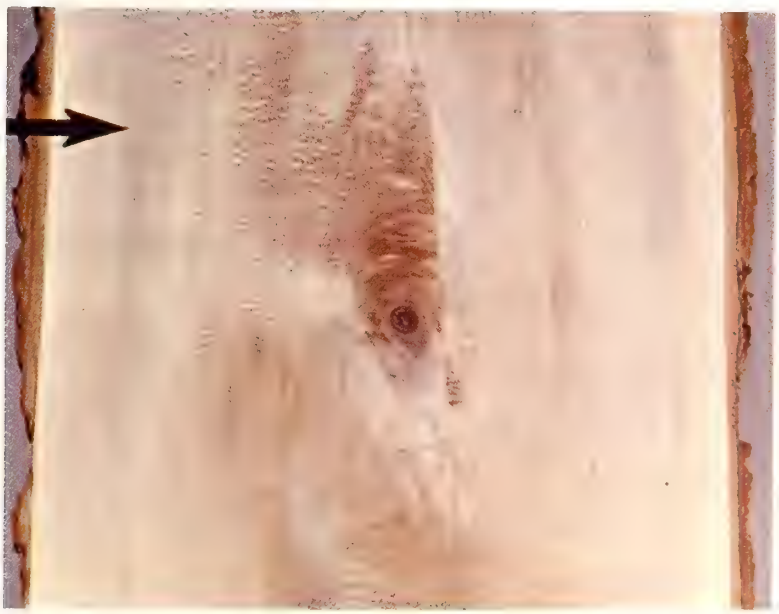
BARK DISTORTION

F-519250

A bark distortion is an interruption in the normal bark pattern; it may be a distinct horizontal break, or it may merely be a faint change in arrangement of plates and fissures. The distortion is usually circular and sometimes slightly elevated above the surrounding surface. The faint bark distortions are commonly overlooked by graders, but often even these have underlying defects. The bark distortion may be a late stage in the healing of another defect, such as an overgrown knot or an epicormic branch.

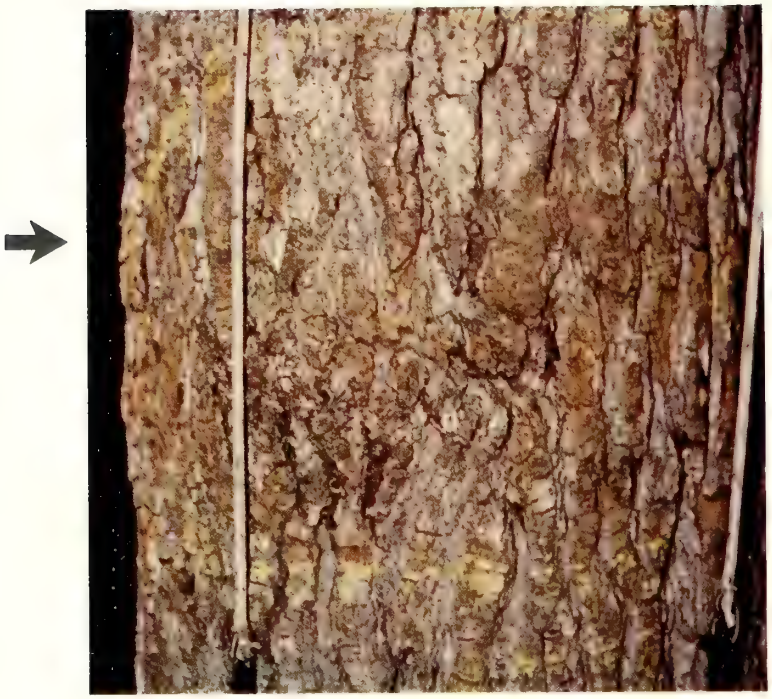


Depth 3 inches F-519251



Depth 4 inches F-519252

BARK DISTORTION



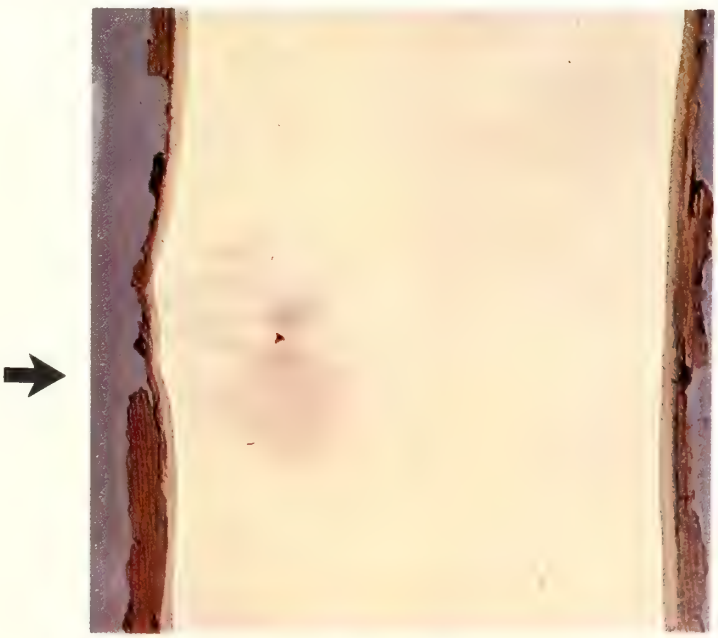
F-519253

Depth 1 inch F-519254

Depth 3 inches F-5

BARK DISTORTION

F-519256



Depth 3 inches F-519257

EPICORMIC BRANCH

F-519742

Epicormic branches normally appear as small sprouts on the bole of the tree. Overgrown epicormics are characterized by a puckered circular pattern with a distinct center.

EPICORMIC BRANCH
(Overgrown)

1 inch

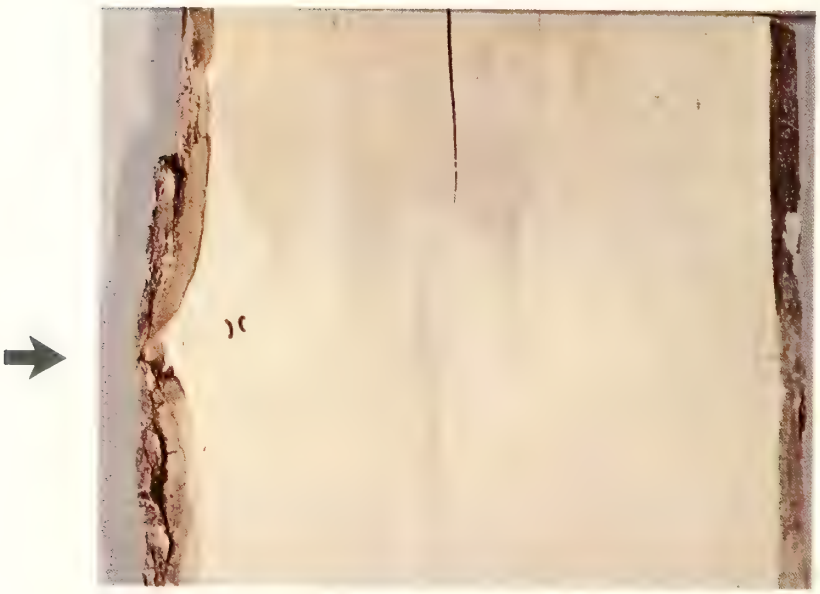
F-519259

Depth 2 inches

F-519260

EPICORMIC BRANCH
(Overgrown)

1 inch F-519261



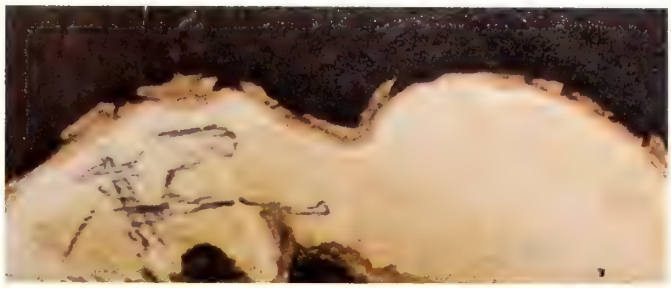
Depth 3 inches F-519262

FLUTE

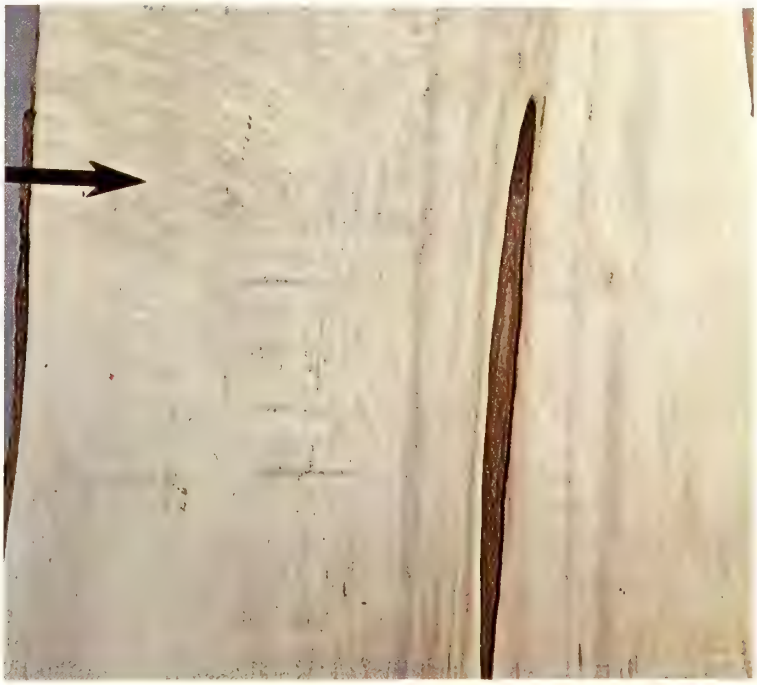
F-519263

1 inch

View of cross-cut section



1 inch F-519265



Depth 3 inches F-519264

Flutes are narrow vertical depressions of varying length and depth that contain unbroken bark. They generally begin and end within the first 8 feet of the tree bole.

OPEN SEAM

F-519266

Open seams are vertical radial separations of the wood fibers that are not overgrown with callus tissue or wood and bark. They are generally caused by wind, lightning, or frost.

View of cross-cut section

Depth 2 inches F-519267

F-519268

OVERGROWN SEAM

F-519269

Depth 1 inch F-519270

View of cross-cut section

F-519271

Overgrown seams are vertical radial separations of the fibers that are overgrown with callus tissue or wood and bark. They are generally caused by wind, lightning, or frost.

OPEN WOUND

F-519272

Open wounds are damaged areas on the stem where the bark has been removed, exposing the sapwood and sometimes the heartwood. These wounds can be caused by falling trees, by trees or limbs rubbing against each other, by logging equipment, and by animals. A triangular wound at the base of a tree is referred to as butt scar.

Depth 3 inches F-519273

Depth 4 inches F-519274

Depth 5 inches F-519275

OVERGROWN WOUND

F-519276

Overgrown wounds are damaged areas on the tree stem that are overgrown with callus tissue or wood and bark. The wounds are caused by falling limbs and trees, logging equipment, and animals.

Depth 1 inch F-519277

Depth 2 inches F-519278

CALLUS OVERGROWTH

F-519279

F-519280

Callus overgrowth indicators appear similar to bumps and surface rises except that they are not completely overgrown with bark. They have ridges of exposed woody callus that tend to overlap to one side of the wound. Although they usually cover wounds, they are distinctly different in appearance from overgrown wounds.

Depth 3 inches F-519281

Depth 4 inches F-519282

Depth 6 inches F-519283

BURL

F-519284

F-519285

A burl is a circular, abnormal woody growth with smooth or corrugated surfaces. Burls range in size from small knobs to large growths that may encircle the stem.

Depth 2 inches

F-519286

BIRD PECK

F-519287

Bird peck refers to holes made in trees by sapsuckers. These holes may extend to different depths in the bark, or completely through the bark into the cambium layer. When fresh, the holes are open and not occluded by callus tissue. Older peck holes may be partially occluded or completely filled with callus tissue. Bird peck holes usually exhibit a horizontal row pattern on the stem, but occasionally the holes are distributed randomly.

Depth 2 inches

F-519288

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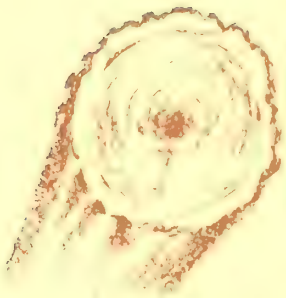
ESEARCH PAPER NC-38

970

estimating



SUGAR MAPLE BARK THICKNESS AND VOLUME

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CHARLES L. STAYTON
and
MICHAEL HOFFMAN

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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Estimating Sugar Maple Bark Thickness and Volume

Charles L. Stayton and Michael Hoffman

Estimating bark thickness is a requirement for tree quality assessment. Knowing the volume or weight of bark within the tree, log, or cordwood pile is important because bark cannot be combined with wood for many products. Bark is also becoming a usable material, and thus the demand for accurate methods to estimate its volume is increasing. Meyer (1946) developed mathematical equations for estimating bark thickness and volume:

$$(1) \quad B = D/2\ (1\text{-}k)$$

$$(2) \quad Vb = V\ (1\text{-}k^2)\ ,$$

where B is bark thickness, V_b is bark volume, D is usually d.b.h.o.b., but could be d.o.b. at any point on the tree, V is total stem volume including bark, and k is the regression coefficient for the relationship of d.i.b. (d) to d.o.b. (D). [1] Meyer plotted d as a function of D and obtained a constant ratio with a straight line passing through the origin of coordinates. Thus, the constant k is determined by the equation

$$(3) \quad k = \frac{\Sigma d}{\Sigma D} = \frac{\Sigma D - \Sigma 2B}{\Sigma D} \ .$$

We tested Meyer's equations to see how accurately they estimate bark thickness and volume for sugar maple (*Acer saccharum* Marsh.). In addition, we developed and tested the accuracy of equations that relate bark thickness and volume to average tree diameter outside bark, d.b.h.o.b., and total merchantable volume. Information is also presented on variation in bark thickness and k up the stem, and weight and volume of bark as a percentage of total merchantable stem weight and volume.

PROCEDURE

Forty-five trees in each of two sample areas, located approximately 200 miles apart, were felled and bucked into 8-foot

---

[1] The d.i.b. and d.o.b. measurements are usually taken at d.b.h. A Swedish bark gauge is used to measure double bark thickness, which is subtracted from d.o.b. to obtain d.i.b.

logs. [2] Tree age ranged from 92 to 289 years, averaging 192 years; d.b.h. ranged from 11 to 26 inches, averaging 18 inches; and tree growth rate ranged from 6 to 23 rings per inch of diameter, averaging 13 rings per inch.

We measured d.i.b., d.o.b., and bark thickness on cross-sectional discs sawed from the butt end of each log. Bark thickness values were determined by averaging four measurements taken at 90 degree intervals. Bark thickness, d.i.b., and d.o.b. were recorded at 8-foot intervals up the stem, and log bark volumes were totaled to get bark volume per tree.

The relationship of d.i.b. to d.o.b. was then plotted. The Y-axis intercept was not equal to zero, but was close enough to assume $k = d/D$, as reported by Meyer. Values of k were calculated for each 8-foot interval up the stem using the d/D ratios obtained from each cross-sectional disc. An average k value was then calculated and used in Equations 1 and 2 to estimate average bark thickness and bark volume for each tree, which were compared to measured values. The average k value is different from that used by Meyer, because he did not take into account variation of d/D up the stem; he measured this ratio only at d.b.h. We also used a different value for D in Equation 1. Meyer used d.b.h.o.b. for D, but we calculated an average d.o.b. per tree.

$$(4) \quad D = \left(\frac{4V}{\pi L} \right)^{1/2},$$

where V is total merchantable volume including bark and L is merchantable length. Because V was obtained for each tree by summing the log volumes, D is a good representative average diameter.

In addtion, because published data [3] show that bark thickness of various hardwoods and softwoods is related to tree size, age, site, and height, we related measured bark thickness and volume of the 90 trees to tree stem characteristics. All possible combinations of the following six independent variables were tried: stem length, average tree diameter (see Equation 4 for definition), d.b.h., tree age, merchantable stem volume, and (stem volume/stem length)$^{1/2}$. The R^2 values and residuals obtained for the regression runs were used to evaluate the accuracy of the developed equations.

To further test the accuracy of Meyer's equations and those we developed, a field test was made. Bark thickness and volume data were collected for 42 new trees located where Sample 1 trees were cut. A Swedish bark gauge was used to obtain bark thickness at 1 foot, 8 feet, and 16 feet above stump (fig. 1). Diameter outside bark measurements were also taken at these tree heights. We then estimated average bark thickness and bark volume for these trees using first our equations, then Meyer's Equations 1 and 2 (using the k value of Sample 1.) These estimates were then compared to the measured values.

We also investigated the rate of change of k and bark thickness with increased height above stump to see if equations could be developed to estimate bark thickness at any tree height. (Meyer's

2 The top log was not always 8 feet because total merchantable stem, based on a 6-inch d.i.b. minimum top or where the tree separated into two or more distinct branches was utilized.

3 (Hale 1955, Klepac 1958, Krier and River 1968, Miller 1961, Minor 1953, Myers 1964, Spada 1960).

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Figure 1.—Collection of field test data. Bark thickness was obtained at various tree heights by using a Swedish bark gauge.

Equation 1 and those we developed give average bark thickness.) In addition, we calculated the average weight and volume of bark for sugar maple.

ESTIMATING BARK THICKNESS AND VOLUME

Meyer method.—The mean k values for Samples 1 and 2 were 0.929 and 0.934, respectively. These two k values, when used in Equations 1 and 2, where D and V were mean average tree diameter and merchantable stem volume for the 90 trees, give only slight differences for bark thickness and volume estimates. Thus, the average k value for the 90 trees, 0.932, was used in Equations 1 and 2 to estimate an average bark thickness and bark volume for each of the 90 trees. Estimated bark thickness was closely correlated with measured bark thickness (r=0.73), and estimated bark volume was closely correlated with measured volume (r=0.95).

Our method. — The equations we developed, using all combinations of six tree stem characteristics as independent variables, also gave good estimates of average bark thickness and bark volume. Average tree diameter can be used to estimate bark thickness — R^2 was almost as high as that obtained using all six independent variables combined. Average tree diameter and tree age combined do give a R^2 value equal to that obtained using all variables. Tree volume, d.b.h., and age were also significantly related to bark thickness (table 1). Bark volume was closely related to total merchantable stem volume (R^2 = 0.91); adding variables did not improve the relationship. Average tree diameter and d.b.h. were also related to bark volume (table 1).

Table 1.—*Some tree stem characteristics that are significantly correlated with bark thickness and volume*

Dependent variable		Increases with	R^2 Sample 1	R^2 Sample 2	R^2 All 90 trees	Equation (All 90 trees)
Average bark thickness	a.	Average tree diameter	0.65	0.46	0.51	$Y = 0.1986+0.0206\ (X)$
	b.	D.b.h.	.55	.44	.49	$Y = 0.2232+0.0153\ (X)$
	c.	Total merchantable volume	.57	.48	.44	$Y = 0.3759+0.0022\ (X)$
	d.	Tree age	.28	.36	.29	$Y = 0.3094+0.0010\ (X)$
	e.	Average tree diameter (X_1) plus tree age (X_2)	.66	.50	.57	$Y = 0.1555+0.0170\ (X_1) + 0.0005\ (X_2)$
Bark volume	f.	Average tree diameter	.81	.69	.75	$Y = -5.5267+0.8767\ (X)$
	g.	D.b.h.	.79	.72	.74	$Y = -4.6542+0.6601\ (X)$
	h.	Total merchantable volume	.92	.92	.91	$Y = 1.0614+0.1104\ (X)$

Field testing both methods. — Meyer's equations and those we developed (a and h from table 1) gave almost identical accuracy when they were used to estimate average bark thickness and bark volume for each of the 42 new trees – r = 0.80 for bark thickness, and r = 0.93 for bark volume. These results indicate that both methods are acceptable.

BARK THICKNESS VARIATION

Bark thickness at a specific tree height is often needed when appraising timber. However, we were unable to develop accurate equations that predict bark thickness (or k, which can be used to calculate bark thickness) at a specific tree height. We found, on the average, that k decreases with increased height above stump (fig. 2), and that bark thickness decreases with height in the first 30 percent of merchantable stem length and then remains almost constant (fig. 3). If the trees are grouped by age class, bark thickness decreases with increased height above stump for the younger trees, but remains almost constant for the oldest trees (fig. 4). However, if regression analysis is used to relate bark thickness or k to height above stump, the variation about the regression line is tremendous (R^2 values range from 0.001 to 0.31). Therefore, general trends can be shown for change in bark thickness or k by height above stump, but the variation is too great to establish usable equations.

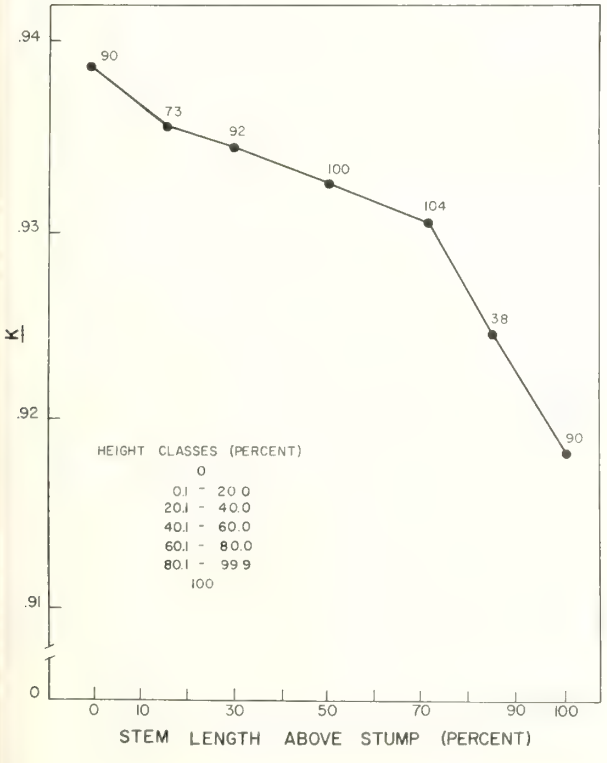

Figure 2.—Relation between K and height above stump. Figures at each point show number of observations.

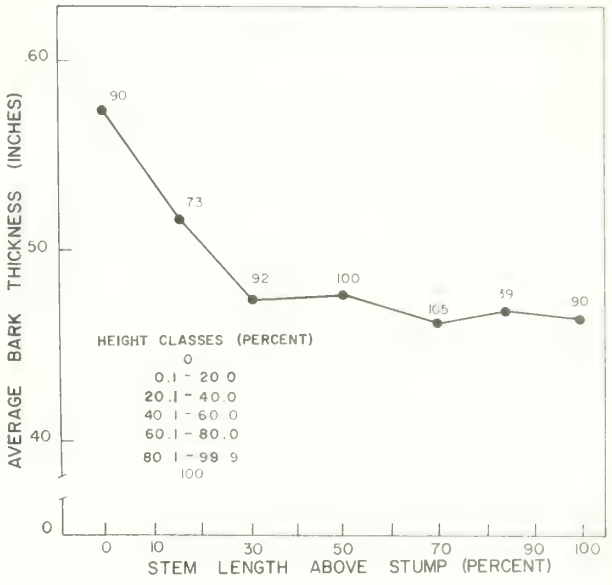

Figure 3.—Relation between bark thickness and height above stump. Figures at each point show number of observations.

Our difficulty in predicting bark thickness at specific tree heights may have been due to differences in bark structure among trees. Sajdak (1968) defined four bark types for sugar maple – platy, shell, corrugated, and ropy. We found bark structure

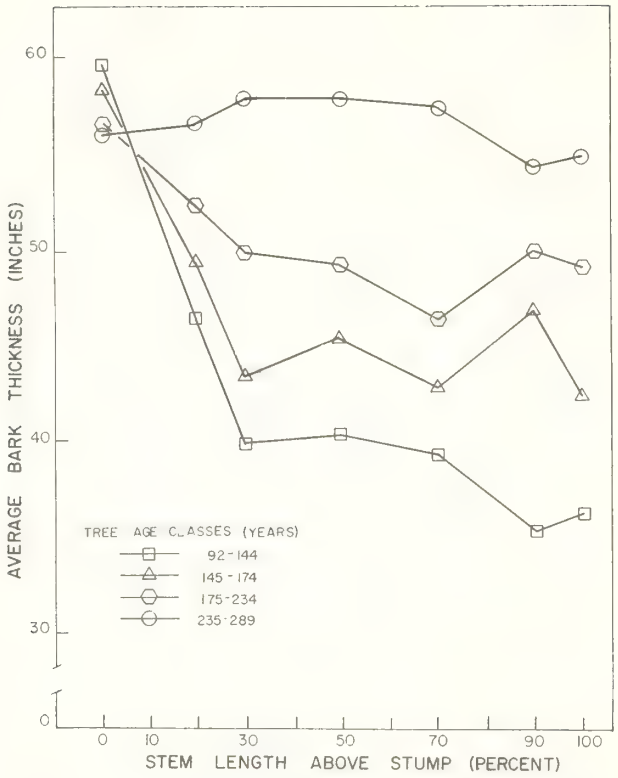

Figure 4.—Relation between bark thickness and height above stump by tree age classes. Percent stem length classes are the same as those given for Figures 1 and 2.

differences during our field test (fig. 5). Sugar maple trees may have to be grouped by bark types to improve bark thickness estimates at different tree heights.

BARK VOLUME AND WEIGHT

For the 90 trees sampled, the average amount of bark per tree was 7.38 cubic feet, or 13 percent of the merchantable stem volume including bark. This percentage is less than a reported value of 18 percent for old growth sugar maple (Gevorkiantz and Olsen 1951). We cannot explain the difference, however, because the method for calculating the 18 percent was not given.

The specific gravities (based on green volume and ovendry weight) of sugar maple wood and bark have been determined previously (Lamb and Marden 1968, 1969). Using these specific gravities and our calculated bark and wood volumes, we found that the weight of sugar maple

F-519662, 519663

Figure 5.—Sugar maple bark structure varies greatly. These two trees were only 5 yards apart and had about the same diameter.

bark is 12 percent of the merchantable stem weight. Hardy and Weiland (1964) gave an average bark weight percentage of 15.5 for northeastern sugar maple. Their value, however, is based on the weight of the wood rather than wood plus bark, and they used green weight for both bark and wood. We get a bark weight percentage of 14 when total merchantable weight excludes bark.

CONCLUSIONS

We found Meyer's equations (modified by use of different k and D values) to be accurate for estimating average bark thickness and bark volume for sugar maple trees. Our equations, based on direct relationships between bark thickness, bark volume, and tree stem characteristics, also gave accurate estimates. Both methods should be helpful in appraising timber and estimating the amounts of wood and bark in standing timber.

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U.S.D.A. FOREST SERVICE
RESEARCH PAPER NC-39
1970

White-tailed Deer in the Midwest

A SYMPOSIUM, presented at the 30th Midwest Fish and Wildlife Conference, Columbus, Ohio
DECEMBER 9, 1968

NORTH CENTRAL
FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

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FOREWORD

Research at the North Central Forest Experiment Station is concerned with developing forest management systems to favor all kinds of forest resources, including wildlife, so we welcomed the papers of the deer symposium reported here. The fact that the participating researchers added their personal opinions to the factual data presented adds value for research planning.

We are happy to publish this timely contribution to the understanding of deer management problems in the Midwest.

D. B. KING
Director

PREFACE

When I accepted the assignment as Technical Game Session Cochairman of the 30th Midwest Wildlife Conference, I did so with the thought that here was an opportunity to consider and discuss an important, and largely neglected, aspect of wildlife management — the nonyarding white-tailed deer population of the Midwestern United States. Deer in the agricultural-hardwoods belt of the Midwest have not received the attention given their yarding cousins to the north. This is not difficult to understand. To a great extent, we have permitted deer populations of the midwestern farm belt to grow "like Topsy," since they have not yet been nearly the management problem that our yarding deer have been.

Others agreed with the importance of this topic, and the biologists I contacted were willing to participate in the symposium. Mr. Dean A. Murphy, Deer Research Biologist, Missouri Department of Conservation, was asked to report on deer range appraisal. Mr. Charles M. Nixon, Forest Game Research Biologist, Ohio Division of Wildlife, was selected to discuss deer populations. Dr. Hewlette S. Crawford, formerly Wildlife Ecologist, North Central Forest Experiment Station, now with the Southeastern Forest Experiment Station, Blacksburg, Virginia, agreed to report on deer habitat. And Dr. David H. Jenkins, Chief of Research and Development Division, Michigan Department of Natural Resources, was selected to discuss harvest regulations and population control. Mr. Louis J. Verme, Game Research Biologist, Michigan Department of Natural Resources, agreed to be the panel moderator.

Perhaps the most significant contribution of this symposium is that for the first time we have looked upon the deer of this vast area as a more or less discrete population. We know a great deal about our farm belt deer; much remains to be learned, however. Hopefully, this symposium will be a first step in arriving at management programs to meet the challenges of the next few decades.

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WHITE-TAILED DEER IN THE MIDWEST

A Symposium

Presented at the 30th Midwest Fish and Wildlife Conference

Columbus, Ohio

December 9, 1968

INTRODUCTION

LOUIS J. VERME
Michigan Department of Natural Resources
Shingleton, Michigan

This symposium deals with the present status and future prospects of the white-tailed deer *(Odocoileus virginianus)* in the Midwestern United States. This region encompasses the southern portions of Michigan, Wisconsin, and Minnesota, plus all of Ohio, Indiana, Illinois, Iowa, and Missouri. However, it is also appropriate to include the Dakotas, Nebraska, Kansas, and those provinces of Canada having sizable herds of white-tails on primarily agricultural range.

I emphasize at the outset that this symposium deals only with nonyarding deer; that is, animals which, because of favorable habitat conditions and relatively mild weather, usually are not confined in sites of heavy cover for any extended winter period. They may, of course, temporarily band together for safety, or for other reasons still poorly understood. Nevertheless, this is in sharp contrast to the distinct yarding behavior of deer in the northern Lake States region. Because most of my experience has been with yarding deer in the cedar swamps of Michigan's Upper Peninsula, I accepted the task of panel moderator with some trepidation. Fortunately, the panelists have prepared excellent reports on the subject of nonyarding deer.

Perhaps prior to this decade, an "in-depth" discussion of midwestern deer would have seemed premature and largely superfluous. Obviously, most of our attention was, and to some extent still is, directed toward managing the vast herds on the northern ranges. Presently, however, considerable research effort is shifting southward, as it should.

The increase of white-tails in the midwestern farm belt occurred rather surreptitiously, and almost unnoticed except by a few biologists. The great reproductive capacity of corn-fed deer, together with favorable land-use practices, changed the picture dramatically. Generally, the small, scattered herds grew rapidly to surprisingly high levels over much of the region. This is fortunate, as herds in the northern Lake States are experiencing a serious population decline. Possibly within several years, for example, the kill of adult bucks in southern Michigan may equal or exceed the number taken above the Straits of Mackinac. And only shotguns are legal arms in the populous lower third of that State.

Today the panelists will endeavor to analyze and summarize virtually everything that is known about midwestern deer. This is quite an accomplishment. Beyond reviewing the literature, they sent questionnaires to various State agencies requesting unpublished, up-to-date reports on specific points of the overall situation. Because the environment and amount of research that has been conducted varies throughout the region, the job of assessing the data received undoubtedly was difficult. Some overlap in material or occasional contradictions are to be expected. The findings to be presented surely will pose more questions than are answered. Yet, the real objective of this symposium is to invite searching criticism and reappraisal of our progress in managing midwestern deer properly.

DEER RANGE APPRAISAL IN THE MIDWEST

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ABSTRACT

That portion of the North-Central United States in which white-tailed deer (*Odocoileus virginianus*) do not concentrate in yards during winter was divided into three broad range classes — Northern Transitional, Agricultral, and Central Hardwoods. The classes were based on differences in land use, forest types, and amount of woody cover. Woody cover was judged to be adequate except in the Agricultural Range Class, where it is being rapidly diminished by competing land use. It was recommended that efforts be directed toward inventorying woody cover, and determining rate of loss and possible methods for preserving existing cover. A review of published data and a questionnaire survey of the States in the region indicated a need for additional information on the basic components of range appraisal. The greatest amount of information was available on food habits of deer. Data were generally inadequate on quantity of forage available, quality of forage, nutritional requirements of deer, forage inventory methods, effects of utilization on forage plants, trends of range condition, and carrying capacity. Additional research was recommended on the effects of even-aged management in oak-hickory forests and on the factors influencing production of acorns and wild fruits.

The biological goal of white-tailed deer management is balancing deer population levels with carrying capacity of the range. The goals of deer range appraisal are: delineating habitat types, determining carrying capacity of the various habitat types, and determining factors influencing carrying capacity. Information needed to achieve these goals includes: (1) distribution and adequacy of woody cover, (2) food habits of deer, (3) quantity of forage available, (4) quality of forage available, (5) nutritional requirements of deer, (6) trends in forage production, and (7) factors influencing forage production. This paper will summarize our present knowledge of the above factors and describe needs for additional knowledge of the habitat of nonyarding deer in the Midwestern United States.

The help of many people was necessary in this attempt to summarize deer range appraisal in the North-Central United States. The following persons responded to my questionnaire and generously furnished publications that I might have otherwise overlooked: Paul D. Kline, George F. Hartman, David H. Jenkins, John M. Idstrom, Richard M. Bartholomew, John C. Calhoun, and Charles M. Nixon.

RANGE CLASSES

The range of nonyarding deer in the North-Central United States occupies approximately the southern four-fifths of the region (fig. 1). Range types within the nonyarding area can be separated into three broad classes according to forest types and amounts of forest area (fig. 1). For purposes of discussion, I have named these range classes (1) Northern Transitional, (2) Agricultural, and (3) Central Hardwood.

The Northern Transitional Range Class occupies the northern edge of the nonyarding area and is a gently rolling to hilly transition zone between the boreal forest types (spruce-fir, aspen-birch, and northern hardwood) and the Agricultural Range Class. About 40 percent of the area is wooded.

The Agricultural Range Class occupies the central part of the nonyarding area. It is characterized by a limited amount of forest cover (less than 20 percent) and level to gently undulating topography. Woodlands generally are present as scattered woodlots of oak-hickory or as bottomland hardwoods (elm-ash-cottonwood-sycamore) along streams.

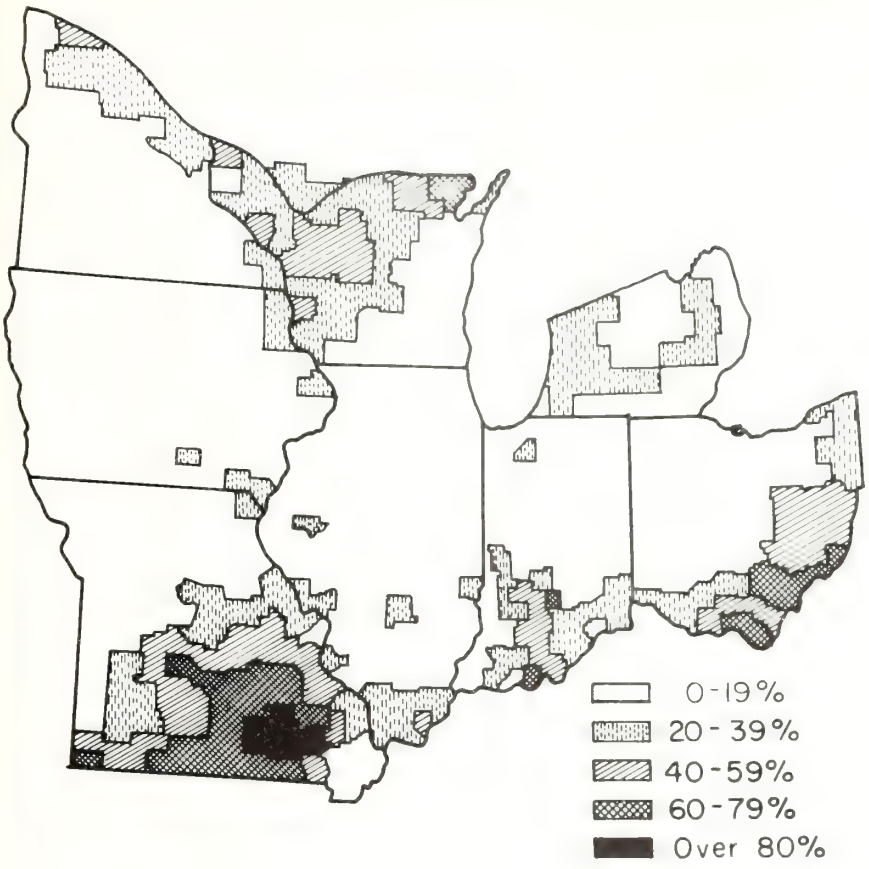

Figure 1. — Forest cover in the Midwest.

The Central Hardwood Range Class occupies the generally hilly southern portion of the nonyarding area. Oak-hickory forests are predominant and generally occupy more than 50 percent of the land area. Some beech-maple forests occur in the eastern part of this range class, and oak-pine stands are found in the southern portion.

Climate is variable over the region. Temperature extremes range from —30° F. to +105° F. but are of short duration. Frost-free seasons vary from 160 to 210 days. Precipitation ranges from 25 to 60 inches, with annual short droughts common in the south. Annual snowfall ranges from 10 to 15 inches in the south to over 50 inches in the north (DenUyl 1962, p. 144).

DISTRIBUTION AND ADEQUACY OF COVER

Woody cover is probably adequate in the Northern Transitional and Central Hardwood Range Classes. In some areas, such as the eastern Ozarks of Missouri where forests occupy over 80 percent of the land, cover may be more than adequate because large solid blocks of timber are not optimum deer range.

Deer and forests have always been related in the minds of men. However, the rapid increase of deer in the Agricultural Range Class has demonstrated that deer can adapt to astonishingly small amounts of woody cover. A prime example is in Iowa, where deer have increased in numbers and distribution (Kline 1965) even though the average county in Iowa is only about 8 percent forested. However, the acreage of woody cover cannot be considered adequate throughout the Agricultural Range Class. More of the total land area could be occupied by deer if additional woody cover were available.

The distribution of woody cover as shown by aerial photos was one criterion used by the Wisconsin Department of Natural Resources in determining the number of square miles of deer range in each deer management unit.[1]

FOOD HABITS

Some of the earliest food-habit studies consisted of compiling lists of foods eaten by deer. These lists

[1] *Personal correspondence with A. D. Doll, Wis. Dep. Natur. Resources.*

showed that deer eat a great variety of foods. Atwood (1941) listed 614 plants eaten by white-tailed deer. His references from the midwestern region showed 204 plants taken by deer. More detailed studies of forage utilization and analyses of deer rumens showed that, although deer sampled many foods, a few items generally constituted the major portion of the diet. A major consideration in any food-habit study is, "Do the findings represent preference (palatability) or availability of food items?" I believe that "habit" or "custom" may influence deer utilization of different plants in different areas.

Northern Transitional Range Class

Food-habit studies are relatively limited, but the available information indicates that deer eat mainly native forage and take agricultural crops when available.

Dahlberg and Guettinger (1956, p. 254-255) presented a checklist of 110 trees and shrubs browsed by deer in Wisconsin. Plants were rated as first, second, third, or fourth choice. The first choice plants in southern and central Wisconsin were red maple (*Acer rubrum*), staghorn sumac (*Rhus typhina*), alternate-leaved dogwood (*Cornus alternifolia*), wintergreen (*Gaultheria procumbens*), and wild cranberry (*Vaccinium oxycoccos*).

Erickson *et al.* (1961) reported on the contents of nine rumens from deer in west-central Minnesota. Corn (*Zea mays*), rose (*Rubus* sp.), smooth sumac (*Rhus glabra*), wolfberry (*Symphoricarpos* sp.), green plant parts, and gooseberry (*Ribes* sp.) were the most important items by volume.

Agricultural Range Class

Food-habit studies based on rumen analyses indicate that agricultural crops, especially corn and soybeans (*Glycine max*), form a major portion of deer diets in this range class.

Mustard and Wright[2] found that cultivated crops made up 56 percent of the diet, by volume, in Iowa. Corn accounted for 40 percent and soybeans 13 percent. Buckbrush (*Symphoricarpos* sp.), oak, and apple (*Pyrus malus*) were the major browse items.

Cultivated crops made up 48 percent of the food volume of deer rumens from western Ohio (Nixon and McClain 1968). Corn composed 34 percent, acorns 14 percent, wild crab (*Pyrus coronaria*) fruits 14 percent, and soybeans 12 percent by volume of 168 deer rumens. Wild fruits and seeds also were major food items.

Rumen analyses of 138 deer from northern Missouri (Korschgen 1962) showed that although 41 percent of the total volume was agricultural crops, oak leaves and acorns (25 percent) were as important as corn (21 percent). Forbs (14 percent) and browse and wild fruits (12 percent) were also important.

Although food-habit studies are not available, crop damage complaints furnish an index to deer use of agricultural crops in southern Minnesota and Wisconsin. Corn (50 percent of claims), truck crops (20 percent,) hay (9 percent), and oats (*Avena sativa*) (9 percent) were the crops damaged most frequently in Minnesota (Erickson *et al.* 1961).

Wisconsin pays indemnity for damage by deer. From 1931 through fiscal year 1966-67, the Wisconsin Department paid $778,129 for deer damage. Claims annually exceeded the funds appropriated for damage payments. The largest percentage of claims involved small grains and truck gardens (20 percent each). Soybeans and hay (19 percent each) were the other major crops damaged. Corn constituted only 9 percent of the claims.

Central Hardwoods Range Class

Food-habit studies indicate that deer in this range class utilize native forage (acorns, wild fruits, forbs, and woody browse) more than cultivated crops.

Fruits and seeds constituted 61 percent of the volume of deer rumens from northeastern Ohio (Nixon and McClain 1968). Farm crops constituted only 18 percent of the diet. The most important items were wild crab, acorns, and corn.[3] Dexter *et al.* (1952) found apples, soybeans, and corn to be important food items in 90 deer rumens from northeastern Ohio.

In the hill counties of southeastern Ohio, woody vines, especially Japanese honeysuckle (*Lonicera japonica*), are important deer foods (Nixon and McClain 1968). Rumen analyses showed that woody vines (16 percent by volume), forbs (17 percent), and fruits and seeds (40 percent) were much more important than cultivated crops (9 percent). Wild crab, honeysuckle, corn, greenbrier (*Smilax rotundifolia, S. hispida, S. glanca*), and sumac (*Rhus copallina, R. glabra*) were the most important items.

Preferred deer foods in Indiana were listed by Allen (1955) as poison ivy (*Rhus radicans*), sassafras (*Sassafras* sp.), mints (*Labiatae*), plantain (*Plantago* sp.), honeysuckle, greenbrief, sumac, and wild grape (*Vitis* sp.).

Rumen analyses of deer from the Missouri Ozarks also illustrated the dependence of deer on native forage (Korschgen 1962). Acorns were the most important single item. They comprised 53 percent and

[2] *Mustard, E. W., and Wright, V. Food habits of Iowa deer. 1964. (Unpublished report by Iowa Conserv. Comm., Pittman-Robertson Proj. W-99-R-3.)*

[3] *Personal correspondence with C. M. Nixon, Ohio Div. of Wildlife.*

54 percent, respectively, of the volume of deer rumens in the eastern and western Ozarks. Farm crops made up only 5 percent of the volume in the eastern Ozarks and 3 percent in the western Ozarks. Corn was not identified in any of the 80 rumens from the western Ozarks. Other important foods were forbs (including grass and sedge), browse, and wild fruits.

A different approach to deer food-habit studies in the Missouri Ozarks was taken by Dunkeson (1955). He followed semitame deer in an enclosure and recorded the plants they ate. His study indicated that forbs constituted the largest single class of deer food on an annual basis. Browsing on woody shrubs also extended over a long period of time, but much of the browsing in winter was incidental to consumption of fruits or seeds. Acorns were important when available, and seasonal use was made of ferns, grasses, and mushrooms. Basal rosettes of aster (*Aster* sp.) and goldenrod (*Solidago* sp.), along with pussy-toes (*Antennaria plantaginifolia*), provided green food throughout the winter.

QUANTITY OF FOODS

There is little information available on production of deer food on the various deer ranges under consideration. Food-habit studies indicated that agricultural crops form a major portion of the diet in the Agricultural Range Class. Therefore, a knowledge of the quantities of native foods available probably is not important in that range class.

Deer rely more heavily on native forage in the other two range classes, and a knowledge of quantities available is basic to appraisal of those ranges.

Gysel and Stearns (1968) reported on deer food production under oak stands in central Lower Michigan. Undisturbed 55- to 80-year-old stands produced 200 to 500 pounds (green weight) per acre of browse. Clearcutting of the overstory trees produced yields of 500 to 1,000 pounds per acre. However, a major portion of the increase was oaks and other species listed as third-choice foods by Dahlberg and Guettinger (1956, p. 254-255).

Dalke (1941) reported green weights of deer browse from three cover types in the Missouri Ozarks. Average production was 140 pounds per acre in the post-oak (*Quercus stellata*)-blackjack oak (*Q. marilandica*) type, 111 pounds in the black oak (*Q. velutina*)-hickory type, and 61 pounds in the ravine type.

An extensive survey of deer forage on National Forest lands in the Missouri Ozarks[4] gave estimates of deer food production by forest types, stand-size stocking classes, and various other factors. The quantity of deer food available was quite low in most forest types. The study was made before even-aged management was adapted for hardwood stands and applies only to those stands that have not been cut as prescribed by the even-aged management guide (USDA Forest Service 1962).

Basic to any analysis of the quantity of food available is an understanding of the daily requirements of deer. Although no studies have been conducted within the boundaries of the region under discussion, the findings of several studies are pertinent. Jenkins and Bartlett (1959) stated that Michigan deer in winter required 4 to 7 pounds of food daily per hundred pounds of body weight. Dahlberg and Guettinger (1956, p. 76) concluded from pen studies that Wisconsin deer required 3.5 to 5.5 pounds of browse per hundred pounds of body weight. Duvendeck (1962) found that penned deer in northern Michigan ate 4 pounds of good browse per hundred pounds of body weight and would consume 1.5 pounds of acorns per hundred pounds of body weight per day when acorns were available.

The importance of acorns, fruits, and seeds to deer in the Midwest was evident in our discussion of food habits. Additional information is also needed on yields of these important food items. Christisen and Korschgen (1955) reported a potential average yield of 20 pounds per acre of mature, insect-free acorns from an ordinary stand of oaks in the Missouri Ozarks.

QUALITY OF FOODS

Data are also limited on quality of deer foods available in our area of discussion. There can be little argument that corn and soybeans are high-quality foods; therefore, such studies for the Agricultural Range Class are unnecessary.

However, in the areas where deer are more dependent on native foods, quality of forage may be important. As Dahlberg and Guettinger (1956, p. 76) stated, "Browse plants of high palatability do not necessarily have a high nutritional value." Chemical analyses of preferred winter deer browse plants from the Missouri Ozarks are a good example (table 1). Woody browse in winter probably should be considered as a maintenance diet. Deer supplement this diet by eating (when available) acorns, fruits, and over-winter rosettes of perennial forbs (table 1).

A knowledge of the chemical composition of deer foods is not sufficient, however, to determine their true values. To fully evaluate the results of chemical analyses of browse species, the digestive coefficients of the various plant species should be determined (Forbes *et al.* 1941). This knowledge also is limited for foods eaten by deer in the Midwest. The use of artificial rumens and *in vitro* digestion may offer a solution to this problem (Short 1963).

[4] *Murphy, D. A., and Crawford, H. S. Wildlife foods and understory vegetation in Missouri's National Forests. Missouri Dep. Conserv. Tech. Bull. 4, 55 p. 1970.*

Table 1. — *Chemical analyses of some preferred winter deer foods in Missouri Ozarks*
(In percent)

Plant species	Protein	Fat	Fiber	Ash	C	P	K
Red cedar *Juniperus virginiana*	7.08	11.02	24.42	3.70	1.17	0.12	0.49
Dwarf sumac *Rhus copallina*	4.49	7.53	27.35	4.05	1.42	.10	.58
Smooth sumac *Rhus glabra*	4.71	6.75	25.25	4.90	1.68	.13	.90
Fragrant sumac *Rhus aromatica*	5.36	4.03	32.31	3.46	.71	.11	1.01
Low blueberry *Vaccinium vacillans*	4.39	4.16	36.66	2.26	.65	.08	.35
Sassafras *Sassafras albidum*	5.09	3.41	36.19	1.83	.53	.09	.30
Shortleaf pine *Pinus echinata*	6.68	6.98	23.55	2.55	.27	.12	.41
Aster (rosettes) *Aster* sp.	18.31	3.41	8.19	9.04	.89	.26	2.77
Goldenrod (rosettes) *Solidago* sp.	11.81	3.43	9.33	7.82	1.03	.18	.84

Quality of deer range is reflected in physical development and reproduction of deer. The body weight of fawns (Murphy and Coates 1966, Verme 1963), antler development of yearling males (Severinghaus *et al.* 1950, French *et al.* 1955), and reproductive rate of females (Cheatum and Severinghaus 1950) are indicators of range quality. Body weight of fawns (fig. 2) indicates several different qualities of range in the Midwest.

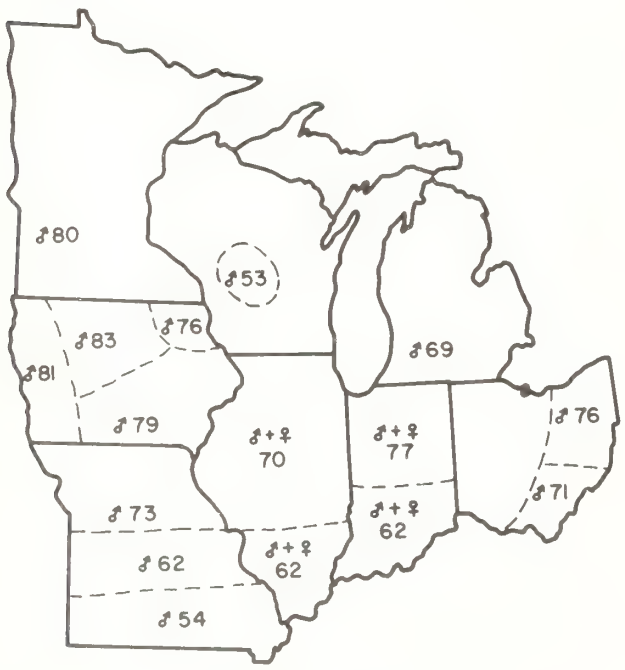

Figure 2. — Range quality in the Midwest as shown by body weight (Field-dressed) of fawns.

Different qualities of deer range within individual States also are indicated by the above criteria, and several States have divided their deer ranges accordingly (fig. 2). These divisions also generally correspond to other criteria for land classification, such as forest cover, soil type, and land use. The superior quality of foods in the Agricultural Range Class is demonstrated by higher average fawn weights and practically no yearling males with spike (unforked) antlers (table 2).

Table 2. — *Antler development of midwestern deer*

Area	Percent of yearling males with unforked antlers
Iowa (statewide)	Almost 0
Northern Illinois	0
Northwestern Ohio	0
Northeastern Ohio	0
Southeastern Ohio	0
Northern Missouri	3
Southern Michigan	5
Central Illinois	5-8
Central Missouri	12
Southern Illinois	21
Southern Missouri	21
Southern Minnesota	--
Southern Wisconsin	Varies annually

In Missouri, we theorized that the differences in physical development and reproductive rate were related to quality of forage as influenced by soil fertility.[5] However, analyses of browse plants from two

[5] *Dunkeson, R. L., and Murphy, D. A. Missouri's deer reproduction and check station data. (Paper presented at 15th Midwest Wildlife Conf., Chicago, 7 p. 1953.)*

regions with significantly different physical development of deer failed to reveal differences in chemical composition of the forage. We are now beginning to suspect that the observed regional differences may be related more directly to the amount of cultivated crops in the deer diet. Therefore, soil fertility is related to quality of deer range by its influence on land use.

NUTRITIONAL REQUIREMENTS OF DEER

This subject could be a symposium in itself, and I will not attempt to discuss it. A very good summary of the relationship of deer nutrition to deer range appraisal was presented by Dietz (1965). It should be recognized that a deficiency in any of the basic elements of nutrition can be as limiting to carrying capacity as can a quantitative shortage of food.

MEASURING VEGETATION AND CONDITION TRENDS

Dasmann (1948) classified range land surveys as (1) forage inventories, (2) range condition trends, and (3) forage utilization checks. This classification appears applicable to deer range appraisal in the Midwest. In other words, the deer range manager needs to know what is available, what is being used, and the effect of this utilization plus other influencing factors. Changes in vegetation occur slowly and subtly. Therefore, they are hard to measure, and even harder to demonstrate.

The methods reviewed by Dasmann (1948) were for California deer range, and few of them are applicable to the midwestern deer range. More applicable to our area are some of the methods of measuring understory vegetation discussed at a symposium in Georgia (USDA Forest Service 1959). The "in-depth" discussions at the symposium illustrate the fact that I can merely scratch the surface of measuring techniques in this paper.

My survey of the Midwestern States indicated that direct methods of range appraisal are not being applied in most of the nonyarding area. Most of the States seemed to be relying on indirect methods, such as harvest data, highway kills, crop damage complaints, or physical measurements of the deer herd. Calhoun reported that range condition studies in Illinois have proved of little value.[6] This statement appears to apply throughout the corn and soybean deer range.

Forage Inventories

Dalke (1941) used the clip-and-weigh method for determining browse production in three cover types in Missouri. Ehrenreich and Murphy (1962) used the double sampling method (Wilm *et al.* 1944) in surveying deer forage production on National Forest lands in Missouri. The method proposed by Aldous (1944) proved applicable in Missouri Ozarks; it provided a basic knowledge of plant composition, species utilized, and degree of utilization in winter. However, the method proved too time consuming for statewide surveys. Data from the Aldous method indicated that only 10 species of plants were used consistently and heavily in winter. Therefore, we have been using belt transects and tallying only the major browse species as an index of browse utilization. The percentage of preferred species browsed is also a rough index of deer population densities (Murphy 1961).

Range Condition Trends

Bartholomew reported that exclosures had been established in Indiana, but the deer population had never reached a level where effects of utilization could be measured.[7] Exclosures were used by Dalke and Spencer (1944) in a study of overused deer range inside a fenced area in southern Missouri. The study indicated that appreciable improvement in range condition had not occurred even after 16 years of protection from grazing. Murphy used exclosures to measure effect of utilization on smooth sumac and elm in Missouri.[8] Dunkeson (1955) used the line-intercept method (Canfield 1944) to study trends in condition of forbs and shrubs browsed during summer in the Missouri Ozarks.

Forage Utilization

The "key area" concept of deer range appraisal in the yarding deer areas and mountainous areas of the Western United States is not applicable to the nonyarding deer areas. The "key species" concept appears to have more application. Dunkeson (1955) proposed that three shrubs which are browsed most of the year —New Jersey tea (*Ceanothus americanus*), wild hydrangea (*Hydrangea arborescens*), and wild grapes (*Vitis sp.*) — may be sensitive indicators of overutilization in Missouri's Ozarks. Deer practically eliminated wild hydrangea on the Crane Naval Depot in

[6] *Personal correspondence with J. C. Calhoun, Ill. Dep. Conserv.*

[7] *Personal correspondence with R. M. Bartholomew, Ind. Dep. Natur. Resources.*

[8] *Murphy, D. A. Unpublished Pittman-Robertson report on file with the Missouri Dep. Conserv., Columbia, Missouri.*

Indiana.[7] Pietsch (1954) reported that all available sassafras and dogwood (*Cornus sp.*) were eliminated on an island in the Horseshoe Lake Game Refuge in Illinois.

Measurements of annual twig growth before and after browsing were used to determine degree of utilization and effects of utilization on preferred winter browse plants in Missouri.[8] Relating the amount of twig growth utilized to twig counts can be used also as a measure of browse production (Shafer 1963). This method needs further evaluation for use in midwestern deer range.

If game management is to progress in our increasingly complex society, we must develop game management from the art that it has been to a recognized science. The ability to measure accurately is basic to a science. In measuring forage production, we have the opportunity to advance towards scientific accuracy. The statistical approach should be utilized in experimental design, sampling, analysis, and interpretation of all forage measurements (Evans 1962). A competent statistician, preferably with biological training, should be involved in all phases of the project.

INFLUENCING FACTORS

Economics, land use, forestry practices, and biopolitics are some of the factors influencing the balance between deer populations and deer range. These factors are an intrinsic part of range appraisal. However, they also relate closely to management of deer range and will be discussed more fully by Dr. Crawford.

Woodland grazing by domestic livestock is an important influencing factor, especially in the Agricultural Range Class. Woods in this area are usually in woodlots or stream bottoms, and grazing by livestock is common. In Iowa, where 80 percent of the woodlands are pastured, 27 percent of the forest land is grazed so heavily that no tree reproduction is present and severe erosion occurs (Thornton and Morgan 1959). The percent of woodland pastured is shown for seven Midwestern States below:

State	*Percent of woods pastured*
Illinois	60
Indiana	36
Iowa	80
Michigan	15
Minnesota	—
Missouri	30
Ohio	36

Open range laws in Missouri have permitted grazing cattle and hogs on unfenced forest land. It was only recently that the laws were changed to prevent trespass grazing.

CARRYING CAPACITY

Determination of carrying capacity is the end product of deer range appraisal. Carrying capacity can be defined as the number of animals that a given unit of land area can support. In deer range management the phrase "without deterioration of the forage resource" must be added. Hosley (1956) reviewed carrying capacity of various ranges for white-tailed deer. He reported (p. 225), "Considering the wide range of conditions represented, there is a surprisingly close agreement in the carrying capacities reported. Twenty deer per section or a deer to 32 acres can be taken as an approximate average carrying capacity in the states represented."

A common approach to determining carrying capacity has been to permit the deer herd to increase, usually within a fenced area, until utilization of forage becomes excessive and reproduction and physical condition of the deer herd decline.

Some examples from the Midwest are: (1) Crane Naval Depot in Indiana — 50 deer per square mile eliminated wild hydrangea;[7] (2) Ravenna Arsenal in Ohio — one deer per 20 to 25 acres created a browse line;[3] (3) Fort Custer in southern Michigan — 100 deer per square mile created a browse line in hardwoods, and preferred species were heavily browsed or eliminated;[9] and (4) Drury Refuge in Missouri — 100 deer per square mile created a browse line on red cedar and decreased thrift and abundance of preferred summer browse species (Dunkeson 1955, Murphy 1961). Numerous other examples undoubtedly exist.

The above approach satisfies the first part of the definition of carrying capacity but does not consider the added phrase "without damage to the forage resource." These population densities actually represent a saturation level that exceeds the true carrying capacity of the range.

The true carrying capacity for deer in the Agricultural Range Class will probably never be reached except in isolated local areas. The tolerance of farmers to crop damage will be exceeded long before the deer herds exceed the food supply. In areas where landowners control large acreages, the tolerance level generally will be higher than in areas where landowners control small acreages.

The tolerance level of landowners may also reduce the carrying capacity of some local areas in the Northern Transitional Range Class. Damage to truck crops was among the most frequent complaints in Wisconsin and Minnesota. Farmers growing high-value crops on relatively small acreages are usually very intolerant of deer. Deer populations of 60 to 80

[9] *Personal correspondence with D. H. Jenkins, Mich. Dep. Conserv.*

per square mile of deer range in southern Wisconsin are at present creating excessive crop damage and creating hazards on highways.[10]

Acorns (when available) are a major part of the deer diet in the Central Hardwoods Range Class. The available food supply is increased substantially in years of acorn abundance. However, acorn production is unreliable and good yields do not occur every year. For this reason, I believe that carrying capacity of this range class should be based on yields of preferred native forage, and acorns should be considered only as a bonus in years when they are available.

Our survey of deer forage on National Forest lands in Missouri[4] showed the lowest production in winter, as might be expected. The annual carrying capacity therefore would be limited by the available food supply in winter. Only yields of preferred deer foods were used in calculating carrying capacity, and it was assumed that serious damage to preferred species would occur before other species were heavily used. An allowable utilization of 25 percent of the annual growth was set (other studies showed that this degree of utilization would not reduce the vigor of species involved). The conservative carrying capacity, as calculated using these considerations, was less than eight deer per square mile for the major forest types. The forest type with the widest distribution, black-scarlet oak (*Quercus coccinea*), had a carrying capacity of only three to five deer per square mile.

DISCUSSION AND RECOMMENDATIONS

When I accepted this assignment, I thought I could go to my reference files and find most of the material for the paper. It was quite a shock to find that very few published data were available. Perhaps some of my colleagues are guilty of not publishing their findings, but it appears that most of the basic data for deer range appraisal in the Midwest have not been collected.

The Lake States workers have concentrated their efforts on the problems of the yarding areas and have generally neglected the southern nonyarding deer ranges. Researchers in the Corn Belt States have apparently felt that deer range appraisal was not necessary. Attempts at deer range appraisal have progressed furthest in the oak-hickory forests of the southern part of the Midwest, but even there our knowledge is incomplete.

The absence of woody cover limits distribution of deer throughout much of the Midwest. There is every evidence that this cover will diminish in the future. An effort should be made to inventory present distribution of cover, measure the rate it [illegible] being depleted, and attempt to alleviate the depletion whenever possible.

Research on food habits has received attention in most of the Midwestern States. A knowledge of food habits is a basic first step in deer range appraisal, but the knowledge is worthless unless it can be applied to other steps in the appraisal.

It is the information on other factors essential to range appraisal that is generally lacking. Research is needed on forage production, effects of utilization, and trends in range condition.

Nutritional requirements of deer and the quality of forage should be studied. Quantitative shortages of food probably will not occur in the nonyarding deer range, but quality of range may restrict growth of deer populations.

Acorns and fruits of native trees and shrubs are important components of deer diets in the Midwest. Studies of the factors influencing production of these foods should be initiated.

Livestock grazing in woodlots can destroy their value for deer. Evaluations of this competition and recommendations for alleviating it should be made.

The recently adopted system of even-aged management in the oak-hickory forests will undoubtedly alter deer food production, and research studies of these changes should be undertaken immediately.

The white-tailed deer has demonstrated an amazing ability to adapt to apparent habitat deficiencies. However, if we are going to provide the number of deer required to meet demands of the ever-increasing number of hunters, deer range appraisal must be more complete and recommendations for range management more detailed. The techniques for securing most of the missing links are available, but manpower and financing must be made available to do the job.

[10] *Personal correspondence with G. F. Hartmann, Wis. Dep. Natur. Resources.*

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DEER POPULATIONS IN THE MIDWEST[1]

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ABSTRACT

Deer *(Odocoileus virginianus)* in the nonyarding portion of the Midwest, including all of Ohio, Indiana, Illinois, Missouri, Iowa, and the southern portions of Minnesota, Wisconsin, and Michigan, were nearly exterminated by 1910. Protection, improved habitat, and restocking provided the impetus for rapid increases after 1930. By 1968, there were nearly 850,000 nonyarding deer in the Midwest. Present populations are highest in central Wisconsin, central Minnesota, the Missouri Ozarks, and southern Michigan; they are lowest in the Corn Belt States of Ohio, Indiana, Illinois, and Iowa. Trends in highway deer kills since 1963-64 show that herds in Iowa and Minnesota are nearly stable while herds in the remaining States have been increasing between 10 and 20 percent per year. The nonyarding deer population in the Midwest will probably reach 1 million by the early 1970's. Continued destruction of deer habitat will cause deer populations to stabilize and begin to decline within the next decade.

This paper attempts to survey the present status of the nonyarding deer herds of the Midwest. I am restricting this discussion to the deer herds of Ohio, Indiana, Illinois, Missouri, Iowa, and the central and southern portions of Michigan, Wisconsin, and Minnesota. Winter weather seldom restricts deer movement in this range, and except for enclosed herds, refuge populations, and the southern Missouri Ozarks, an overpopulation of deer and associated range deterioration has never occurred. Deer densities are well below those of more northern herds, and large deer populations are a fairly recent phenomenon.

Less than 5 percent of this region is in public ownership, and intensive human utilization of most of the land for industrial or agricultural purposes creates conflicts with expanding deer herds. Queal's (1968, p. 51) statement, "Rural landowners can directly influence the management and harvest of deer in agricultural areas because of their attitudes toward deer and deer hunter access on their lands," is true for most nonyarding Midwest range.

I wish to acknowledge the cooperation of the following biologists who generously supplied information concerning the status of deer in their respective States: Richard Bartholomew, Indiana Department of Natural Resources; Dr. Richard Andrews, Eastern Illinois University; David Arnold, Michigan Department of Natural Resources; Dean A. Murphy, Missouri Department of Conservation; William Creed and George Hartmann, Wisconsin Department of Natural Resources; Paul Kline, Iowa Conservation Commission; and John Idstrom, Minnesota Department of Conservation.

HISTORICAL REVIEW

After settlement began, deer populations increased in much of the region as pioneer clearings temporarily improved deer habitat by opening the virgin forests (Pietsch 1954, p. 4). After 1860, however, the ever-expanding human population and concurrent removal of forest cover, along with year-round hunting, exterminated deer from all of Ohio, Indiana, Illinois, Iowa, and southern Michigan by the early 20th century. Only small scattered populations were present in southern Wisconsin and Minnesota and in the Ozarks of Missouri. In 1910, the Midwest population, exclusive of captive herds, probably totaled less than 2,000 deer.

Restocking, improved law enforcement, conservative hunting regulations, and reforestation of abandoned agricultural land combined to favor the reestablishment of deer. Restocking in the Corn Belt States was augmented by movement into unoccupied range from rapidly increasing adjacent herds (fig. 1). Deer moved south from Michigan into northern Indiana and Ohio (McNeil 1962, p. 29), from western Pennsylvania into northern Ohio,[2] from the Missouri Ozarks into central Illinois (Pietsch 1954, p. 7)

[1] *A contribution of Federal Aid in Wildlife Restoration Project, Ohio W-105-R.*

[2] *Chapman, F. The development and utilization of the wildlife resources of unglaciated Ohio. 1938. (Unpublished Ph.D. thesis on file at Ohio State Univ., Columbus.)*

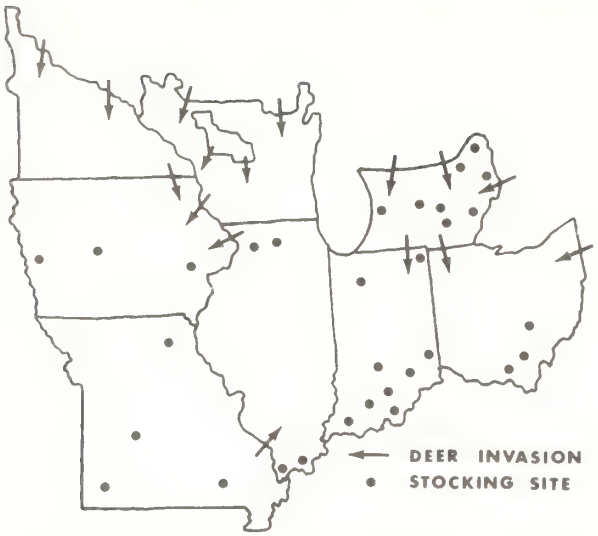

Figure 1. — Principal deer stocking sites and routes of natural restocking in the Midwest, 1920-1960.

and from central Minnesota and Wisconsin south into Iowa and Illinois (Sanderson and Speaker 1954, p. 615, Pietsch 1954, p. 9) (fig. 1). By 1940, at least 21,000 deer were present in the region, localized in the better coverts adjacent to stocking sites (table 1). Populations were largest in Minnesota, Wisconsin, Michigan, and Missouri, and this pattern has continued to the present.

Between 1940 and 1950, the amount of deer range increased considerably in each State. There were at least 80,000 deer in the region by 1950, occupying most of the available range (table 1). Crop damage complaints were increasing in portions of southern Michigan, northeast Ohio, Missouri, and Wisconsin. Highway kills were also becoming more frequent in every State in the region.

Even though liberal hunting regulations and relatively high cropping rates in Ohio and Indiana in the early and mid-1950's slowed deer population increases in these States, the Midwest herd increased to over 270,000 deer by 1960 (table 1). The Missouri herd, in particular, quadrupled in a decade.

Except for Illinois, deer herds continued to increase throughout the region during the 1960's, and by fall of 1968 the nonyarding range of the Midwest supported an estimated 845,000 deer (table 1).

PRESENT DISTRIBUTION

In general, present deer population densities in each State reflect land-use patterns and human population distribution (fig. 2). Deer populations are much higher in Missouri, Wisconsin, Minnesota, and Michigan than in the Corn Belt States. Average densities per square mile for each State show that Wisconsin leads with nearly eight deer per section, while Ohio and Illinois have the lowest densities, about one deer for each two sections (table 1). Deer are present in virtually every county in the Midwest, but

Table 1. — *Estimated prehunting fall deer populations in the Midwest, 1940-1968*

State	Area	1940	1950	1960	1968	Deer per sq. mile 1968
	(Sq. miles)					
Ohio	40,000	2,000	12,748	8,000	22,000	0.55
Indiana[1/]	36,291	800	3,000	17,000	40,000	1.10
Illinois[2/]	56,400	500	3,100	19,195	25,000	.44
Missouri[3/]	69,674	4,500	42,000	170,000	320,000	4.59
Iowa[4/]	56,280	1,000	4,500	22,468	38,000	.68
S. Michigan[5/]	22,300	5,000	15,000	30,000	80,000	3.59
S. Wisconsin[6/]	31,834	--	--	--	250,000	7.85
S. Minnesota[7/]	36,000	7,500	--	--	70,000	1.94
Total		>21,300	>80,348	>266,663	845,000	

1/ Allen (1950, p. 139); Crail (1954, p. 55); personal correspondence with R. Bartholomew, Ind. Dep. Natur. Resources.

2/ Pietsch (1954, p. 8, 11).

3/ Personal correspondence with D. Murphy, Missouri Dep. Conserv.

4/ Sanderson and Speaker (1954, p. 615); Kline (1965, p. 212); personal correspondence with P. Kline, Iowa Conserv. Comm.

5/ McNeil (1962, p. 12, 40); personal correspondence with D. Arnold, Mich. Dep. Natur. Resources.

6/ Personal correspondence with W. Creed, Wis. Dep. Natur. Resources.

7/ Erickson et al. (1961, p. 5); personal correspondence with J. Idstrom, Minn. Dep. Conserv.

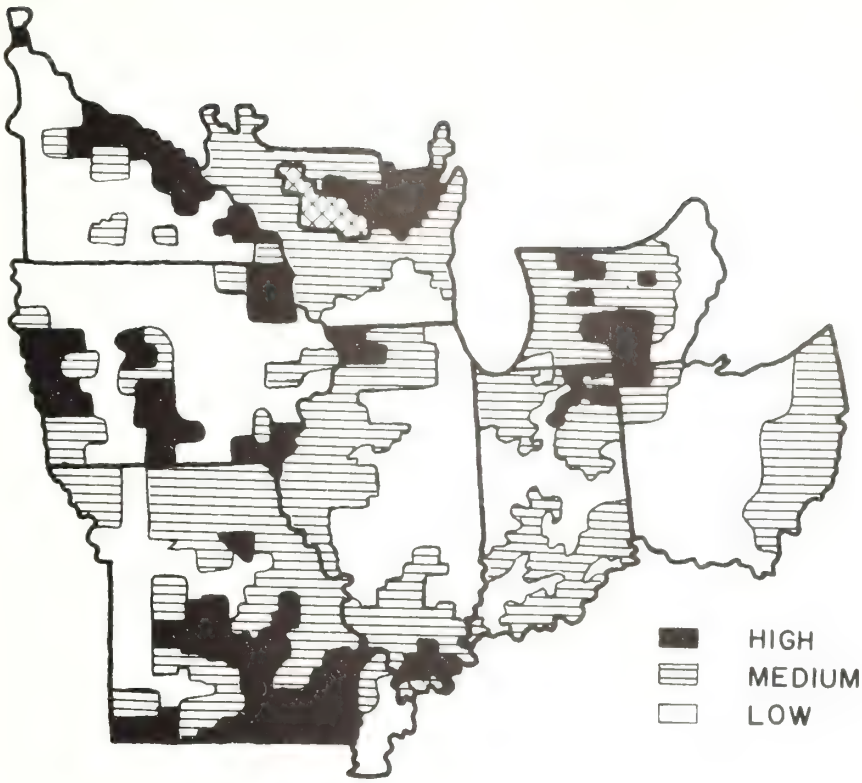

Figure 2. — Distribution of midwestern deer herds in 1968. Densities are comparable only within each State; i.e., high densities in Iowa do not compare with high densities in Missouri. The cross-hatched area shown in central Wisconsin represents central forest range and was not included in this survey.

local populations vary considerably from the statewide figures — from 60 to 80 per section in portions of Wisconsin to near zero in many counties in the Corn Belt (table 1).

RECENT TRENDS

Jahn (1959, p. 190) and Nixon (1965, p. 137) found annual highway deer kill useful as a means of showing population trends but not as a precise index of annual change. McNeil (1962, p. 24) also found the highway kill comparable with other indices of herd status.

A rate of population change may be estimated by linear regression using natural logarithms of the annual highway deer kill for a number of years if correction is made for the annual increase in highway construction and vehicular travel (McNeil 1962, p. 24). For Ohio, at least, highway traffic and new highway construction have been increasing about 2.5 percent per year and have been fairly consistent since 1953.[3]

[3] *Russell, K. Deer harvest patterns in Ohio. 1969. (Unpublished report on file at Ohio Div. Wildlife, Columbus.)*

The rate of change in highway deer kills shown in table 2 for each State is therefore slightly higher than the actual growth rate in each herd. On the basis of highway kill trends, the Minnesota and Iowa herds have been relatively stable since 1963-64, while the remaining herds have been increasing between 10 and 20 percent per year since that time (table 2).

MORTALITY

Mortality rates were calculated on the basis of fall population estimates and known mortality by various categories supplied by State conservation departments. Hunting is the leading cause of death in midwestern deer herds, followed by poaching, automobile collisions, dog predation, and miscellaneous deaths (table 3). States such as Illinois and Iowa that permit taking deer of either sex each fall and contain a limited amount of winter cover show the highest mortality (table 3). The rapid increase in the Missouri deer herd can be explained by the low annual mortality of this herd (table 3). Except for the Minnesota and Illinois herds, the mortality rates shown in table 3 seem to conform to the highway kill trends shown in table 2.

The slow increase in the Minnesota highway deer kill since 1964 would indicate that annual mortality

Table 2. — *Annual rate of increase in highway deer kills in the Midwest, calculated by use of natural logarithms (Loge) to compute linear regression*

State	Years	Rate of change	Deer population density
		(Percent)	(Rank)
Ohio	1963-67	+20.7	7
Indiana	1/1964-67	+13.3	5
Illinois	1/1963-67	+13.4	8
Missouri	1/1963-67	+18.1	2
Iowa	1/1963-67	+ 7.9	6
S. Michigan	2/1963-67	+15.1	3
Wisconsin3/	1/1964-67	+15.7	1
Minnesota3/	1/1964-67	+ 4.4	4
Average		+13.6	

1/ Thompson, F. Deer on highways, 1967 supplement. 1968. (Unpublished report on file at New Mexico Dep. Fish and Game, Santa Fe.)

2/ Arnold, D. Deer killed by cars, southern Michigan. 1968. (Unpublished report on file at Mich. Dep. Conserv., Lansing.)

3/ Highway kill for the entire State used because specific information for the southern portions was not available.

Table 3. — *Annual mortality rates for midwestern deer herds*
(In percent)

State	Harvest	Illegal	Highway	Dogs	Misc.1/	Total
Ohio	2/ 6.7	6.7	7.3	<1.0	<1.0	21-22
Indiana3/	4/10.5	10.5	1.5	<1.0	<1.0	23-24
Illinois5/	6/31.6	--	5.4	--	--	>37.00
Missouri7/	2/ 9.0	<1.0	<1.0	<1.0	<1.0	10-12
Iowa8/	6/30.0	10.0	3.0	<1.0	<1.0	43-44
S. Michigan9/	2/13.6	13.6	5.1	1.9	1.3	35.50
S. Wisconsin10/	2/25.2	<1.0	3.3	<1.0	<1.0	29-30
S. Minnesota11/	6/18.6	<1.0	2.3	<1.0	<1.0	22-23

1/ Train collisions, disease, fawn loss, fences, drownings, falls.

2/ "Hunter's choice" (deer of either sex) allowed in some portions of the State and "bucks only" in other portions.

3/ Personal correspondence with R. Bartholomew, Ind. Dep. Natur. Resources.

4/ Buck hunting only.

5/ Personal correspondence with J. Calhoun, Ill. Dep. Conserv.

6/ "Hunter's choice" statewide.

7/ Personal correspondence with D. Murphy, Missouri Dep. Conserv.

8/ Personal correspondence with P. Kline, Iowa Conserv. Comm.

9/ Personal correspondence with D. Arnold, Mich. Dep. Natur. Resources; McNeil (1962, p. 65).

10/ Personal correspondence with W. Creed, Wis. Dep. Natur. Resources.

11/ Personal correspondence with J. Idstrom, Minn. Dep. Conserv.

is higher than is shown in table 3. Based on the age structure of the southern Minnesota herd (Erickson *et al.* 1961, p. 21), an annual mortality rate near 40 percent would be needed to hold down population growth to the level shown by the highway kill. According to Andrews and Calhoun (1968), portions of the Illinois herd were overharvested beginning in 1965. However, highway kill trends for the entire State do not show a decline, although annual increases in highway kill have been small since 1966.[4]

The enclosed, protected herd on the George Reserve in southern Michigan can sustain an annual removal of 39 percent (Chase and Jenkins 1962, p. 78). Andrews and Calhoun (1968, p. 7) present evidence that a legal harvest greater than 35 percent resulted in an excessive mortality rate and subsequent population decline in one county in southern Illinois. If harvest management objectives include increasing the population, these data suggest that the legal harvest in nonyarding herds of the Midwest should not exceed approximately one-third of the fall population.

Poaching losses seem to be highest in the Corn Belt (table 3). High human densities and limited range combine to provide good poaching opportunity in these States. Poaching seems to be a definite deterrent to population growth in south-central Ohio and portions of southern Indiana where deer populations are low.[5] In the more northern herds of the Midwest and in Missouri, relatively high deer densities and more extensive deer coverts combine to limit poaching losses.

Deer collisions with automobiles are a serious problem throughout the Midwest. In portions of Wisconsin, Ohio, and Michigan adjacent to urban areas, highway kills may nearly remove the annual herd increment. At present, portions of Ohio, Illinois, Michigan, and Wisconsin have significant highway deer kill.

Dog predation is also a problem throughout the region, although direct mortality is probably low. Constant harassment by dogs can lower the carrying capacity of otherwise acceptable deer range. Except for the hound breeds, most farm dogs do not chase deer to the point of death. However, in portions of southeast Ohio and probably in many other areas, dogs frequent nearly all available deer coverts, often on a daily basis.

Parisite infestations or disease outbreaks do not seem to be a significant cause of mortality in midwestern deer. Chapman[2] reported a deer die-off from a *Clostridium* spp. infection in southern Ohio. Missouri and Michigan herds experienced die-offs from epizootic hemorrhagic disease in the 1950s (Fay *et al.* 1956, p. 173). The significance of the widespread serological evidence for leptospirosis in midwestern deer herds has not as yet been demonstrated, but a lowered fecundity caused by the disease is a possibility (Roth 1962, p. 145).

AGE COMPOSITION AND SURVIVAL

The age structure of midwestern deer herds as determined from deer shot by hunters indicates that few deer survive to 5 years. Fawns constitute about 40 percent of the fall population, and between 60 and 70 percent of most herds are less than 2 years old (table 4). Such an age structure indicates a high reproductive rate, and except in the Missouri Ozarks, most herds in the region are capable of nearly a 70 percent annual increase (Kline 1965, p. 212, McNeil 1962). Nearly 7 of 10 doe fawns conceive during their first year; virtually all adult does (1 year of age or older) conceive each year and usually carry twins.

Life tables constructed from fall-harvest data in four States in the region show that the average life expectancy at birth is less than 2 years (table 5). Deer that survive their first hunting season have a mean life expectancy of about 1.67 additional years (table 5). There seems to be a close similarity in overall survival throughout the Midwest if these samples are typical, although survival was somewhat better in southern Minnesota than in the Corn Belt States (table 5).

METHODS FOR ESTIMATING POPULATIONS

The use of sex and age ratios obtained from fall deer harvests for estimating deer populations has wide usage in the Midwest because large samples are easily obtained and annually available. However, cropping rates in each age class may not always reflect actual herd composition. There is evidence that deer less than 2 years of age are more vulnerable to shooting and accidents than older deer (Maguire and Severinghaus 1954, p. 98, Eberhardt 1960, p. 123, and Van Etten *et al.* 1965, p. 59). Fawn:doe ratios may change even during a single hunting season in response to varying levels of hunting pressure (Eberhardt 1960, p. 122), and sex ratios may also change if hunting seasons are set during and subsequent to the breeding season (White and Banasiak 1962).

The validity of fawn cropping rates may be examined by comparing fawn:adult-doe ratios in any year and the ratio of 1½-year-old does to 2½-year-old and

[4] *Thompson, F. Deer on highways, 1967 supplement. 1968. (Unpublished report on file at New Mexico Dep. Fish and Game, Santa Fe.)*

[5] *Personal correspondence with R. Bartholomew, Ind. Dep. Natur. Resources.*

Table 4. — *Age structure of five midwestern deer herds determined from fall harvest data*
(In percent)

State	Year	Fawn	Age			
			1-1/2	2-1/2	3-1/2	4-1/2+
Ohio[1]	1962-64	44.5	24.9	14.1	10.6	5.9
Illinois[2]	1957-66[3]	38.0	30.2	18.8	8.7	4.3
Missouri[4]	1951	39.0	23.0	22.4	9.4	6.1
Iowa[5]	1954-62	41.7	25.5	18.1	8.9	5.8
S. Minn.[6]	1956-57, 1959	41.1	25.9	14.8	9.7	8.4
Average	--	40.1	27.3	17.8	9.2	5.7

1/ Russell, K. Deer harvest patterns in Ohio. 1969. (Unpublished report on file at Ohio Div. Wildlife, Columbus.)
2/ Andrews and Calhoun (1968, p. 3).
3/ Pope County only.
4/ Brohn and Robb (1955, p. 14).
5/ Kline (1965, p. 213).
6/ Erickson et al. (1961, p. 21).

Table 5. — *Life table for four midwestern deer herds compiled from fall harvest data*

Year class	Iowa[1]			Ohio[2]			Illinois[3]			Minnesota[4]		
	l_x[5]	d_x[6]	e_x[7]	l_x	d_x	e_x	l_x	d_x	e_x	l_x	d_x	e_x
1/2	1,000	417	1.64	1,000	445	1.69	1,000	380	1.63	1,000	411	1.71
1-1/2	583	255	1.45	555	249	1.47	620	302	1.32	589	259	1.57
2-1/2	328	181	1.19	306	141	1.27	218	188	1.11	330	148	1.40
3-1/2	147	89	1.04	165	106	.92	130	87	.98	182	97	1.14
4-1/2	58	37	.86	39	59	.67	43	23	.96	85	54	.86
5-1/2+	21	21	.50	20	20	.50	20	20	.50	31	31	.50

1/ Kline (1965, p. 213).
2/ Russell, K. Deer harvest patterns in Ohio. 1969. (Unpublished report on file at Ohio Div. Wildlife, Columbus.)
3/ Andrews and Calhoun (1968, p. 3).
4/ Erickson et al. (1961, p. 21).
5/ Number of survivors per thousand.
6/ Number of deaths per thousand.
7/ Mean expectation of further life.

older does 1 year later (Eberhardt 1960, p. 35). Comparing these ratios indicates whether or not cropping has been consistent with age structure. Although year-by-year comparisons could not be made, the age structure of Iowa deer would indicate a cropping rate close to the actual age structure of the herd, because little difference was found between the fawn:adult-doe and yearling:adult-doe ratios (Kline 1965, p. 213). In northeastern Ohio for the years 1962-1964, fawn:doe ratios were much higher than yearling:adult-doe ratios, indicating too high a proportion of fawns in the kill in relation to actual numbers in the herd.[3]

Population densities of several herds have been estimated using the age structure of deer shot in the fall. If deer are harvested in proportion to their representation in the herd, then estimates based on following an age class to extinction may be useful in backdating population growth (McNeil 1962, p. 33, Andrews and Calhoun 1968). At least 5 years would be required in most midwestern herds. The accuracy of this method is also dependent upon accurate aging over several years and over a wide geographic area.

Direct counts of deer are in use only in Missouri and Ohio; both States use aerial censuses on selected

areas when snow conditions permit. Ohio also uses track counts made 24 to 48 hours after a fresh snow in selected townships scattered throughout the deer range. About 144,000 acres are checked each year, and at densities below five deer per section such counts are quite accurate. There has been close agreement between these counts and known reproduction and mortality in the study townships.

Landowner interviews are used in Missouri, and conservation officer estimates are solicited each winter in Indiana and Iowa to determine population status. At low densities (less than five deer per section) these estimates are good trend indicators, but at higher densities year-to-year changes may be difficult to detect unless they are drastic.

Indiana is presently the only State in the Midwest utilizing pellet counts in nonyarding range. Pellet counts have not been utilized to a greater extent in the region because: (1) The number of plots and manpower needs are prohibitively high at low deer densities, (2) low density estimates often produce confidence intervals greater than the mean estimate, and (3) in the southern portions of the region at least, heavy deciduous leaf cover and lack of snow make pellets hard to see and their age hard to estimate.

DISCUSSION

The high deer densities in Michigan, Wisconsin, Missouri, and Minnesota are the result of restrictive harvests, high deer productivity, favorable habitat, and a "protectionist" landowner attitude. Human tolerance of large deer herds can be high, even when crop damage is frequent, and extensive crop damage promotes more hunting opportunity because landowners desire higher deer kills and better herd control (Queal 1968, p. 68). However, in terms of human tolerance, deer herds in both Michigan and Wisconsin are approaching or have exceeded a maximum density for farmland range. Crop damage and collisions with automobiles are high in both States, and cropping rates, which thus far have lagged behind population growth, are being liberalized to reduce deer populations in problem areas.

Population control has not been a problem in the remainder of the region. Short "hunter's choice" seasons have usually been effective in controlling bothersome herds.

Populations in Ohio (Nixon 1963, p. 68), Indiana (Haller 1953) and Illinois (Andrews and Calhoun 1968) have lagged behind those in the remaining States because of high legal harvests during the 1950's in Ohio and Indiana and 1960's in Illinois, and because of high nonhunting mortality, chiefly poaching. At low densities poaching can be an effective population depressant (Crail 1954, p. 55). Deer populations are presently increasing in both Ohio and Indiana under more restrictive harvest regulations (table 1).

With an annual mortality rate of [illegible] percent, the Iowa herd appears to have been relatively stable in recent years, for the annual mortality is nearly equal to the annual increment.

Missouri has one of the largest herds in the Midwest, and has in the sparsely populated Ozarks the best potential for even higher densities without the conflicting human activities that limit other herds. However, the present carrying capacity of much of the Ozarks is less than eight deer per section.[6]

In nearly all of the region, but particularly in Ohio, Indiana, Missouri, and southern Michigan, deer herds will continue to increase, at least for a few more years. The nonyarding deer population in the Midwest may well reach 1 million by the early 197[illegible]'s. However, an ever-expanding human population in the region must soon begin to erase the range improvement that began accelerating nearly 40 years ago. Particularly in the Corn Belt, continuing woodlot clearing and construction of flood control structures are destroying deer habitat. From central Ohio through central Indiana and Illinois into the prairie and riverbreak range of Missouri and Iowa, forest cover is essential for deer survival.[7]

Even in the better deer coverts of the Midwest, land abandonment and reversion to brush and forest will not continue indefinitely. Deer populations must inevitably decline as forests mature and human activities destroy more range. In Ohio deer concentrations have shifted from northeastern Ohio to the southeastern hills in the past 15 years because of an elimination of habitat in northeastern Ohio. Because of human activities in northeast Ohio there is a significantly higher survival rate for southeast Ohio deer compared with deer from the northeast.[3]

Liberalized hunting, increased nonhunting mortality, and continued loss of habitat will, in all likelihood, at first stabilize and then begin reducing midwestern deer herds, probably within the next decade.

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MIDWESTERN DEER HABITAT

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ABSTRACT

Restocking of white-tailed deer *(Odocoileus virginianus)* in the Midwest has been conducted under conditions of optimum habitat. More intensive use of agricultural and wooded lands will change the habitat, and reduce the area that supports deer populations. Imagination, deviation from standard paths, and sound, meticulous research are needed by the wildlife profession to retain future habitat. It will be retained at the expense of agricultural or timber production. The landowner must be reimbursed if we expect him to forego raising other products to produce wildlife.

The purpose of this paper is threefold: (1) to discuss how past conditions of the habitat affected the range of white-tailed deer; (2) to evaluate how present and future land management changes will affect habitat and the range of deer; and (3) to evaluate measures that can be taken to offset future habitat deficiencies. I wish to thank the moderator, members of the panel, and Dr. Theodore Bookhout for reviewing this paper.

EARLY RANGE CONDITIONS

Since a period of low deer populations about the turn of the century, restocking and natural dispersion have extended deer range outward from a few remnant populations located in generally inaccessible forests into many wooded and agricultural areas throughout the Midwest. Restocking deer into agricultural areas was conducted at a time when the habitat was "ripe" — from the 1930's until the 1950's. Many farms had been abandoned during the droughts and depression of the thirties. Secondary succession on abandoned farms created good deer habitat (Beckwith 1954). On operable farms there were many uncropped areas, such as oak-hickory woodlots, wooded lanes, wide and brushy hedgerows, and wet, wooded bottoms that provided cover. The combination of crops interspersed with mature woodlands yielded year-round food — crops, weeds, and twig and leaf browse during the growing season; crop residue and hard and soft mast during the dormant season. Intense stocking and the interest and support of the local citizenry completed the requirements, and range of the white-tail was extended into agricultural areas over a relatively short time.

Habitat conditions within woodland areas at this time were also favorable for an increased deer herd. Many different oaks (*Quercus* spp.), hickories (*Carya* spp.), and other fruit-bearing trees and shrubs were present. Frequent burning maintained a relatively open understory, with a preponderance of native lespedezas (*Lespedeza spp.*) and other fire-tolerant legumes (Blakey 1937) providing good deer forage.

CHANGES IN AGRICULTURAL LAND

Beginning in the 1940's, the amount of "idle land" on farms began to decrease. The pace of putting idle lands into crops or pasture increased during the 1950's and 1960's in spite of surpluses and government land-retirement programs.

The farmer has been caught in a price squeeze. Costs of operation have gone up while the price received for farm products has not risen correspondingly. Heavy investment in equipment, supplies, and land make it mandatory that every acre produce the maximum or the farmer will not make a profit. Uncultivated land that has crop potential is a luxury he cannot afford. Consequently, hedgerows, woodlots, wooded bottoms, and other areas important to wildlife are being converted to cropland.

In the past, the farmer paid the costs of producing our wildlife. Now he is becoming a businessman concerned with investment input compared with profit output. Farm output per manhour increased 393 percent from a base period of 1940-44 to 1966 (Ackley 1967). Inefficiency has been recognized and is being corrected by small farms merging into fewer, more effective, larger units (Hillman 1967). More fences are eliminated as the farms change from a "few cows

and a few crops" to intensive one- or two-crop systems. Marginal sites become productive when they are fertilized or irrigated. These and other changes are contributing to the reduction of idle acreage and a loss of habitat.

In the next 10 years, agriculture will likely change more than it has in the past 20 years. Two-thirds of the world's people today are hungry. Demographers estimate that by 1985 the world's population will double. A recent book, *Famine, 1975!* (Paddock and Paddock 1967), attempts to show that world food needs will exceed the food supply by 1975, and that starvation will be rampant in many areas of the world. The authors point out that only four nations — Argentina, Australia, Canada, and the United States — will provide enough food suitable for export to the many starving, nonproducing nations, and only the U.S. will produce enough to exceed commercial export requirements.

CHANGES IN WOODLANDS

Many areas of woodland, particularly those on better soils, have been and will continue to be converted to cropland. Flood control programs on many river systems have inundated many acres of wooded deer habitat and also have limited seasonal flooding, making it possible to grow crops on areas that formerly could produce only timber. The remaining woodlands are generally growing on poor soils and steep or stony sites where crop potential is not great and crop production impractical. These woodlands have also changed since the time deer were originally stocked.

The first major change was caused by fire control. When frequent burning was stopped, hardwoods resprouted profusely. Many areas that formerly had desirable herbaceous understory vegetation and fruit-producing understory plants now support dense stands of saplings or poles with little understory vegetation.

Secondly, and probably of less importance, timber management recommendations have suggested the removal of noncommercial species, such as post oak (*Q. stellata* Wang.), or blackjack oak (*Q. marilandica* Muench.), from timber stands. This reduces the variety of mast-producing plants.

Impact of the third, and possibly most important, factor has not yet been felt on many private areas but will be more evident in the future. Even-aged management has been shown to be the best silvical system for growing oaks in the Midwest. This system requires regeneration accompanied by clearcutting, as opposed to the former system of selective cutting. Also inherent in even-aged management is a series of intermediate or thinning cuts.

At first glance, it seems this system would benefit deer range because it involves cutting that opens the stand. However, the response of the understory is affected by site quality and cutting intensity and results are not always beneficial. For instance, an intermediate cut on a poor site may yield only sprouts of oak species that have little food value for deer. On a poor site oaks sprouting from an existing root system could utilize all available moisture, light, or nutrients to the detriment of other species that do not have the advantage of an existing root system.

Management on better sites retained in timber will be more intensive in the future. Superior-growth trees will be planted and grown, with little or no competition either in the overstory or understory. Trees with superior growth characteristics may have inferior fruiting characteristics, and fruit growth might well be suppressed because it utilizes nutrients and water that could go to production of cellulose. A timber stand without fruit production and devoid of understory vegetation has little value for deer.

Not even poor timber sites where it is uneconomical to conduct intensive silvical practices are exempt from change. Millions of acres of poor-site hardwoods are being converted to grassland. The practice is increasing each year as the demand for beef increases and as farmers learn they can greatly increase their return from the land by growing grass instead of scrub timber. A recent study (Crawford and Bjugstad 1967) has shown that 2 tons per acre of native bluestem (*Andropogon* spp.), switch (*Panicum virgatum* L.), or indian grass (*Sorghastrum nutans* L.), or approximately the same amount of Kentucky-31 fescue (*Festuca arundinacea* Schreb.) can be grown on formerly wooded areas having a site index of 55 for black oak. On droughty south and west slopes with site indexes from 35 to 45, native grasses will yield from 1 to 1½ tons; fescue will not do as well.

Patchwork conversion of small acreages could enhance deer habitat by creating diversity, assuming lands were not heavily grazed; however, large ownerships are often completely converted. Thorough conversion and heavy grazing over large, contiguous ownerships will decrease food and cover for white-tailed deer.

On marginal agricultural soils some formerly cultivated land has reverted to woodland. However, part of the reported increase in forest land is actually an increase in brushy pasture or rangeland. For instance, in Missouri about 25 percent of the reported commercial forest land is less than 10 percent stocked with trees and is used to graze cattle (Bjugstad and Crawford 1967).

RETAINING DEER HABITAT

Food needs and technological change of the future are certain to have a substantial impact on the Midwestern United States. This region, one of the most

fertile agricultural areas in the world, contains the Corn Belt, which produces more than 40 percent of the world's corn (Woytinsky and Woytinsky 1953), and the eastern winter wheat belt, a major soft-wheat-producing area. Production, preference, storage, and transport characteristics determine that wheat and corn will be our major exports in attempting to meet the world's food needs. Technological change will continue to increase yields and make it profitable to put more land into agriculture. Rising domestic incomes, growing exports, and new farm policies that more effectively relate production to demand have almost eliminated government surplus (Ackley 1967, Paddock and Paddock 1967) and insure a continuing market.

Less-fertile areas, such as former croplands that have reverted to brush or old fields, will be in demand for food production. Beef-cattle production will increase on these areas just as it is increasing on poor soils where woodland is being converted to pasture and range. Newer, more adaptable pasture plants, such as Kentucky-31 fescue, which respond well to fertilizer and withstand intensive use, are being successfully planted to make productive pastures.

In short, we will be hard pressed to retain any land with agricultural potential for wildlife production with present land management practices. There may be a wealth of summer food and cover, but once crops are harvested little food or cover will remain for deer. The same will probably be true for other game species.

There are two opportunities for retaining deer habitat: (1) modification of agricultural practices, and (2) maximum enhancement of habitat on wooded lands with little agricultural potential. Economics will determine if either or both are possible.

World food requirements will not dictate that wildlife cannot be grown. In our free enterprise system the man who makes his living from the land can grow wildlife instead of wheat or corn if he prefers — but wildlife must pay a return if he is to forego raising agricultural products. Here is the crux of the problem: in the past the farmer has received little or no return from wildlife, but, intentionally or unintentionally, has paid the cost of producing it. Present trends indicate that if the farmer does not receive a monetary return in the future, he will not produce wildlife because of the strong demand for and profit in crop production.

Deer production on wooded areas will be competing with intensive timber production, intensive recreational development, or in some cases, with watershed protection. Additionally, there is the possibility that woodlands will be converted to grass and managed for cattle. In woodlands, just as in cropland, the use that shows the greatest economic return will stand the greatest chance of dominating. I am speaking of privately owned land because the area of public land in the range of nonyarding deer in the Midwest is small compared with the total land area. However, the principle that the use that brings the greatest economic return will dominate may likely apply to public land in the future, and does so now on many public lands.

What steps should we take to retain deer habitat? First, we must modify our thinking on "free" use of the game resource. Someone pays for game production, but our inherited philosophy makes us reluctant to think that the consumer should pay the producer. In the future of the Midwest, the producer will seldom pay for game production; if the consumer refuses to pay, there will be little game.

Another philosophical breakthrough that must be made is placing a monetary value on the wildlife resource for economic comparison. We have to be able to relate the value of a deer herd to the value of corn, timber, or any other competing land use. The comparison is best when direct, and although dollars provide a direct unit of comparison, there has been a past reluctance to assign a dollar value to wildlife because of its intangible value. The intangible value must not be ignored; it must be quantified.

The third step necessary to retain deer habitat is intensive habitat development. Woodlands, where the economic return from wood production is large, will be managed intensively for wood with little left for deer habitat. However, many wooded areas throughout the Midwest will not produce a satisfactory profit from growing wood (Ehrenreich and Ralston 1963, Sherman 1967). With proper management, these areas may produce a more valuable wildlife crop; or, the wildlife crop in conjunction with the timber crop may provide the greatest return. We have to determine the costs of various habitat improvement measures, the economic return expected from increasing deer production on any given area, and the return or loss to wood production.

Any agricultural areas set aside for wildlife production must be managed intensively for wildlife or there is no economic justification for removing it from crop production. We must determine the best way to develop and manage this land. The prime need in agricultural areas will be winter cover.[1] We must determine what cover conditions can support the greatest number of deer. Food needs seem less important but will be affected by efficiency of new harvest systems. The grain and cob of corn are primary

[1] *Mustard, E. W., and Wright, V. Food habits of Iowa deer. 1964. (Unpublished manuscript, Pittman-Robertson Proj. W-99-R-3, on file at Iowa Conserv. Comm.)*

winter foods of deer in the Midwest (Korschgen 1962, Watt *et al.* 1967). If new techniques eliminate crop loss in harvest, as they likely will, deer will depend more upon available crops, such as winter wheat. This dependence will not be at all compatible with farming. An increased supply of natural winter foods, such as acorns and coralberry (*Symphoricarpos orbiculatus* Moench.), will become more important.

The retention of habitat for nonyarding deer in Midwestern United States presents a challenge to the wildlife profession. It will require imagination, deviation from standard paths, and sound, meticulous, nonspectacular (but vital) research. We have to put a sound, acceptable value on deer and see that the landowner receives a return from his wildlife crop. We must determine how to improve the habitat, and show the landowner how these changes will benefit him financially.

I have assumed that the midwestern deer hunter is interested enough in his recreation to pay for it just as he would pay for a day on the golf course. If he is not, then chances are good that he will have to find a different form of recreation or be willing to travel greater distances to hunt.

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HARVEST REGULATIONS AND POPULATION CONTROL FOR MIDWESTERN DEER

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ABSTRACT

In 1967, 149,000 deer were harvested by 629,000 hunters on 399,000 square miles of midwestern "farmland" deer country (in Minnesota, Wisconsin, Michigan, Ohio, Indiana, Illinois, Iowa, Missouri, and Nebraska). In this region, both hunting pressure and deer kill have increased recently. Deer populations on the average range from nearly zero to 5 deer per square mile, with concentrations up to 100 animals per square mile.

Antlerless deer are legal in all States in generally short seasons of different kinds. Shotguns are the legal weapons in most States. In 10 years, almost 1 million deer have been taken (54 percent antlered, 46 percent antlerless). Kill data are obtained by several methods — checking stations and mail surveys mainly.

Illegal kill and landowner-hunter relationships are problems, but serious only locally. Deer managers are generally satisfied with their authority.

Farmland deer are highly productive. To capitalize on this productivity demands landowner-hunter cooperation, controlled hunting pressure, and an adequate annual kill.

What do we mean by population control? In farm country the major means by which white-tailed deer (*Odocoileus virginianus*) populations are controlled are legal hunting, in-season illegal kill, poaching out of season, automobile-deer collisions, fawn mortality, and predation and harassment by dogs. We are concerned here mainly with a discussion of legal hunting because the information available on all of the other losses does not appear to be dependable, comparatively speaking. I have not included data on archery hunting because archers do not make much of an impact on the deer herds in farmland country. The rule to follow in establishing archery regulations is to set up the most liberal regulations possible because the inherently low success rate of archers in itself provides enough protection for an established herd. Further in my opinion, there is no good reason for denying a gun hunter a chance to kill a deer even though he managed to kill one in an earlier bow and arrow season. This chance to kill a second deer is legal in several States and it tends to boost the sport of archery.

This paper is, for the most part, based on information supplied by nine State agencies in response to a questionnaire sent out in the summer of 1968. Information available from the several States doesn't mix very well, and I've ended up with a "windshield survey" of hunting seasons. Data on the deer, the deer range, and the deer hunter for the northern parts of Minnesota, Wisconsin, and Michigan are much more complete than for the southern farmland range. This is natural because much research has been restricted to the large northern herds in these States, while fact-finding projects on the southern herds are relatively new. However, States such as Missouri, Iowa, and Nebraska, with rapidly growing farmland herds, have accumulated a wealth of good data.

When many of us think of deer hunting in the Midwest, we tend to think of the red-coated army headed north into the big woods a day or so before the season — wild-eyed and loaded down with 2- to 3-inch-long cartridges, a case or two of refreshments on the back seat, knives at the ready on the belt, up before dawn in a snow-covered cabin, and out along a cedar-balsam swamp edge, hoping for a crack at a big swamp buck. And you would be right. In spite of the fact that the midwestern nonyarding deer habitat covers almost 400,000 square miles in the lower third of Minnesota, lower half of Wisconsin, and lower half of Michigan, plus all of Ohio, Indiana, Illinois, Iowa, Nebraska, and Missouri, the northern deer range in Minnesota, Wisconsin, and Michigan still provides the most venison and the most recreation — a 1967 legal take of 254,000 deer by 1,017,000 hunters (about 7 hunters per square mile) on 136,000 square miles. This compares with 149,000 deer taken by 629,000

hunters (1½ per square mile) on 399,000 square miles of farms, woodlots, and subdivisions. But, if present trends continue — if the sun keeps shining down and producing wood in the northern forest areas faster than the trees can be cut down, and unless the land can be put back into something resembling deer country instead of a land of porcupines, woodpeckers, and red squirrels — many of us here now might see the day when the farm country deer harvest will outstrip that of the North Woods. Fifteen years ago in Michigan's farm country, 17,800 hunters killed 1,280 bucks, while in the famed Upper Peninsula, 96,400 hunters took 19,260 deer. Last year farmland hunters numbered 105,100 compared with 104,000 in the Upper Peninsula, and their kill was 10,400 deer compared with 24,700 above the Straits. But this 24,700 included 14,000 antlerless deer taken under much-liberalized hunting regulations. Comparative buck harvests tell the story more accurately. The Upper Peninsula buck take fell from 19,260 in 1952 to 17,800 in 1962, and to 10,700 in 1967, while the farm buck harvest climbed from 1,280 to 5,540 in the same years (Bennett *et al.* 1966, Ryel 1968). Something similar can be seen in Wisconsin, but the Minnesota situation seems to be more stabilized.

Public hunting land in the farm country covers only 2 percent of the total land area — 8,256 square miles — compared with 27 percent (29,000 square miles) of the total land area in the northern deer range of Minnesota, Wisconsin, and Michigan. This means, for all practical purposes, deer hunting in the farm country is a private land affair.

People we do have — 47 million of them in the farmland deer country, and they own and operate 25 million vehicles. Twenty-eight million of them live in the cities and suburbs. And 19 million share their land with almost 1 million deer. Censusing deer in farmland habitat is vexing, at best. I think in this respect there is only one "smart" State — Ohio. They say, "We never attempt to arrive at a deer population figure."

There is very little fee hunting for deer — where a landowner charges to hunt deer on his property. Most States report none. Nebraska reported that about 10 percent of their land was under fee hunting and the practice was growing. Missouri also reported about 10 percent of their deer range was under fee hunting, mostly near the metropolitan areas. Wisconsin has two such tracts covering 60,000 acres, one being a group of farms.

In 1967, the 629,000 farmland hunters were not evenly distributed within the region, nor within any State. Wisconsin led with 200,000. Here farmland hunters made up 42 percent of all license buyers. Of the three northern States, Michigan was next with 105,000 hunters. In Minnesota, where deer hunting is still a northern phenomenon, only 18,000 are farm country hunters. Missouri, with 162,000 hunters, stands alone and high among the other States. Illinois, Nebraska, Ohio, Iowa, and Indiana each have from 22,000 to 46,000 hunters. The three northern States determined hunter distribution by postcard surveys of a sample of license buyers. I asked the nine States how many hunters hunted in their farmland deer habitat, and three replied, "All of them." I suppose they took it for granted that we knew exactly what "all of them" meant numerically.

Some idea of hunting pressure in the northern deer range can be obtained by dividing the number of hunters per county or management area by its area in square miles. Farm country is different, and a general figure is meaningless because there are large blocks of land where no one hunts adjacent to areas where there are 20, 40, 80, or 100 hunters per square mile. Missouri reports 200 "nuts" per square mile on a refuge. Other States can boast of similar examples. A few years ago at Fort Custer in southern Michigan, between 700 and 800 individuals spent at least some time on a 2-square-mile area on the opening day of the season. There were no human casualties and, actually, few deer casualties, although any deer surviving something like that should be retired along with the ducks that complete their 25 missions at a shooting preserve!

Concentrations of hunters coincide fairly well with concentrations of deer. Every State reports general farmland deer populations from an average of nearly zero to 5 per square mile, and almost every State has concentration areas with populations of 20 to 50 deer per section with a few areas running up to 80-plus per square mile. Winter concentrations of over 100 deer in a 20-acre cornfield or orchard are not uncommon, to the dismay of the landowners. Also, concentrations of 5 to 20 deer per 100 feet of a two-lane highway are not uncommon, to the dismay of the motorist, as he speeds over the crest of a hill and sees them in front of him.

Every time I review the hunting regulations for any group of States, I am amazed at the provincialism of all of us. Here are nine contiguous States, yet there are major differences in the hunting regulations among almost all. Doesn't that mean something to us? Doesn't it raise questions in our minds as to just how *necessary* some of our regulations are? If something is absolutely necessary in northern Ohio, why isn't it necessary in southern Michigan? And if something is totally unnecessary in southern Wisconsin, why isn't it totally unnecessary in northern Iowa? Sometimes we're forced into silly regulations by our legislatures, or by the public, but are we sure we don't bring it upon ourselves sometimes?

Now, considering only farmland deer hunting regu-

lations—*Minnesota* has its traditional hunter's choice seasons, with short 1- to 5-day seasons in different zones, opening simultaneously, no limit on the number of hunters.

Moving next door to *Iowa* — hunter's choice seasons with the necessary control lying in the number of licenses available and the length of the season in different zones. Two- to 3-day seasons. Licenses issued first-come, first-served until the quota is filled. Resident hunting only.

Southern *Wisconsin* is zoned with 2- to 5-day hunter's choice seasons, plus a later bucks-only season in one of these zones, plus a 9-day buck season and its concurrent antlerless deer hunting by permit-holding parties of four hunters in other areas.

Across the lake in *Michigan:* A 16-day buck season in which permittees may take a deer of either sex in one of several areas. A drawing is held to determine who the permittees shall be.

Ohio: Zones with 4- to 6-day seasons, bucks only with one hunter's choice area in 1968.

Indiana has a 17-day buck season, plus special any-deer hunts on certain military reservations. In some areas hunters may take a second deer.

Illinois: A hunter's choice season in two 3-day periods with 10 days of closed season in between. Resident hunting only.

Missouri: A 4-day season for bucks in some counties and hunter's choice in others, followed by a 10-day closed period, then a 1-week bucks-only season.

Finally, to *Nebraska,* where some zones had a 9-day bucks-only season in 1968, plus some hunter's choice areas and times. All permits are issued under a quota on a first-come-first-served basis.

With the exception of firearms used, hunting regulations in Minnesota, Wisconsin, and Michigan are generally the same for farmland deer as they are for northern deer. With two exceptions (Nebraska and Missouri), the farmland area is shotgun and muzzle loader country. Nebraska insists on rifles only, with a minimum of 900 foot-pounds of energy at 100 yards. They also permit the magnum handguns, plus the old favorite .44. Missouri permits center-fire rifle bullets of not less than 60 grains, plus 20- to 10-gauge shotguns with slugs, and handguns .38 caliber or larger. Twenty-two caliber rim-fire rifles are finally taboo everywhere, and that's progress. Iowa, Illinois, Indiana, Ohio, and Wisconsin say shotguns with slugs only, and Indiana insists on 12-, 16-, or 20-gauge slugs only. Michigan permits slugs or buckshot. Wisconsin adds to the head scratching by insisting in one area it shall be shotguns only on November 23 and 24, but in the same area allows rifles from November 25 to December 1. There *must* be a good reason for this.

The rise of the use of muzzle loaders is refreshing. All nine States permit their use. Missouri, Illinois, and Ohio say they have to be .38 caliber or larger. Nebraska says .40 caliber or larger, Michigan says .41 caliber or larger, and Indiana says .45 caliber or larger. And Iowa says at least .44 but not larger than .775 caliber. They permit no cannonballs in Iowa. Wisconsin and Minnesota both say .40 caliber or larger if the barrel is rifled; .45 caliber or larger if it is a smooth-bore muzzle loader.

It seems to me that keeping the rural residents and schoolbus drivers happy and unafraid is the only good reason for the shotguns-only regulation. In Michigan, and I suspect other States would find the same, 85 percent of all deer hunting gun accidents occur at ranges less than 100 yards (well within range of a 12-gauge slug). Sixty-five percent of the accidents occur at ranges less than 50 yards, at which distance size 0 buckshot will do more than raise a welt on you. And 50 percent of our accidents occur within range of a bean shooter (10 yards).

In general, midwestern farmland deer populations are on the rise, and hunter participation and kill reflect the increase. The *average* annual regional harvest over the past 10 years is in the neighborhood of 90,000 animals. The 1967 total kill of 149,000 animals tops this appreciably. The entire picture in Minnesota and Ohio seems to be stabilized, but in all other areas an upward trend is noticeable. Not in a straight line, in all cases, but upward.

Hunter success varied considerably in 1967, from 70 percent in Minnesota, 56 percent in Nebraska, 36 percent in Iowa, and 30 percent in Wisconsin down to 10 to 14 percent in Illinois, Indiana, Missouri, and Michigan, and further down to 5 percent in Ohio.

Sex and age information on the deer killed in all States is not complete. But over the past 10 years in the region the kill has averaged something like 54 percent antlered bucks and 46 percent antlerless deer, and that is remarkably good. We in Michigan have a long way to go even to catch up to that regional average. In the past 10 years in our farm country, 10 percent of the kill has been antlerless deer. We are trying to correct that, but it's slow.

How the kill figures are determined and the pros and cons of the different systems currently used are grounds for a symposium in themselves. Briefly, there are about as many systems in the region as there are States. Ohio, Illinois, and Wisconsin man compulsory checking stations. Missouri does the same for their any-deer areas but depends on tag returns for the bucks-only areas. Iowa depends on a 95-percent return of hunter report cards. Nebraska has "compulsory" report cards with reminders to nonrespondents. Minnesota has a postcard sample survey. Indiana has a hunter report card system, but states that only one-third of the hunters comply. Michigan has a postcard sample survey with many followup

reminders. Obviously, the systems are dictated by what *we* think is best, our resources, custom, and what our legislatures make us do.

The major drain on the farmland herds is legal and illegal killing of deer. One especially hazy area is the illegal kill, which can be divided into two classes: In-season, accidental and otherwise, and out-of-season poaching. Objective data on these losses are not available except perhaps on small areas, and extrapolation could be misleading and perhaps totally inaccurate.

Minnesota says its illegal kill probably is not serious, but there are no quantitative data. Missouri, also, is not too concerned and places this loss at less than 1 percent of the herd. Wisconsin says illegal kill is bad locally but not statewide. Locally, it amounts to perhaps 10 percent of the fall herd. Wisconsin uses a crippling and illegal loss figure of 25 percent of the legal kill. Ohio believes that the illegal losses make up 10 to 12 percent of the herd's losses in most areas. In south-central Ohio illegal kill is estimated at about 50 percent of all herd mortality. Nebraska says it is bad when the herd is low, but they have no data. Illinois says it is serious locally, but again no data. Iowa considers illegal kill serious, perhaps 2,000 to 3,000 deer per year. Michigan says it is equal to 50 to 100 percent of the legal kill. Indiana states that illegal kill is a major limiting factor to the herd, possibly exceeding all other losses.

Obviousy we know very little about this potentially large loss to the herd. Herein lies one of our major unknowns. What to do about the illegal kill? Maintain as liberal regulations as possible. In farm country, especially, most deer should be legal targets if population levels are adequate.

Are farmer-deer hunter relations an obstacle to establishing good hunting regulations and good deer management? In a word, no. No State reported that trespass problems were serious enough to interfere with management plans, although there were several hotspots reported, especially near population centers. The generally short deer season compared with longer small game seasons makes for a shorter period of farmer anguish, and law enforcement effort can be concentrated. This appeals to many landowners. On the other hand, the short deer season in many States, especially those without the buffer of a more important northern season, concentrates the "madness." Further, the property line ignoring of northern deer hunters does not go over too well with the southern landowners when hunters bring their northern free-ranging habits down into farm country. Gang hunting on isolated plots of cover irritates landowners. Where public and private land is closely mixed, problems arise when hunters either do not recognize the boundaries or do not respect them. A Wisconsin survey showed 24 to 30 percent of farmland was posted against deer hunting.

As the concept of payment for hunting rights gains more acceptance, the landowners will accept hunters more graciously. I support Crawford's thesis (this conference) that the landowner will come to expect a dollar payment for granting permission to hunt. There are direct and indirect signs of this in many States. Obviously, the average landowner will not be able to raise a resident herd of deer like a flock of pheasants or rabbits or quail, but providing attractions for deer plus providing a good place to hunt will be worth more and more and there will be a market for this "product of the land."

Two comparable studies in Michigan in 1960 (McNeil 1962) and 1965 (Queal 1968) revealed significant changes in landowner attitudes concerning deer hunters as the deer herd increased. In 1960, 35 percent of landowners granted permission to hunt. This compared to 52 percent 5 years later. There were significant differences between farmers experiencing crop damage and those who did not. There was also a direct correlation between the numbers of deer seen by farmers and their granting hunter access. Also, where human population is high, granting permission to hunt is low. Naturally, permission to hunt was more easily obtained in the antlerless deer hunting areas in southern Michigan where there is a higher deer population, more crop damage, and more deer seen by landowners.

Are farmland deer managers happy with their lot, with their progress, and with their authority? Generally, yes. And this alone is something worthy of note. Iowa feels that the farmer's free license to hunt on his own property is not desirable. Indiana is still suffering from lack of public support for deer management policies, and this prevents a realistic harvest. Minnesota needs authority from their legislature to have longer open seasons to permit better manipulation of the harvest. Wisconsin suggests that ecologically based management units would be better than their present county boundaries. Further, their party permit system, whereby a party of four licensed deer hunters may kill one antlerless deer in a certain management unit (in addition to one antlered buck per hunter), does not give sufficient flexibility — too many permitholders in some areas, not enough in others. For example, they need individual permitholders in some areas, parties of two in others, and parties of four in others. Michigan is authorized to have antlerless deer hunting in the farmland only to alleviate crop damage or to alleviate highway hazards. This is fine, but these reasons are only legal "excuses" for an adequate deer harvest. The best reason is because deer hunting is an excellent source of recreation in an area where such is sorely needed, and large numbers of deer can and should be harvested legally. It's just plain good sport.

Farmland deer have to compete with a vast array of hazards — Oldsmobiles, fences, "delinquents" with 22's, dogs, bird hunters with itchy fingers, hungry humans disgusted with the rising price of beef and pork, and a growing army of licensed "redcoats." Studies in several States have shown that deer can easily be overharvested in the farm belt. For example, over 40 percent of the fall herd has been legally harvested at times in Illinois (Andrews and Calhoun 1968). Nevertheless, the herds are tremendously productive. Computations in Iowa indicate a gross increase of 70 percent over the spring breeding herd. This computation is substantiated by data from the University of Michigan's 2-square-mile fenced-in George Reserve northwest of Ann Arbor. Here all gains and losses to the herd are known.[1] This area of 40 percent open fields, 35 percent woodlots, 15 percent swamps and bogs, and 10 percent marshes, with a productivity of 18 fawns per 10 adult does and 7 fawns per 10 doe fawns, has produced a 70 percent annual increase — over the last 20 years — and this in turn has produced an annual kill of 21 deer per square mile. Forty-three percent of the total kill has been antlered bucks and 57 percent antlerless deer; or, putting it another way, 65 percent males and 35 percent females.

In the wild some of this production is wasted and conditions are not nearly as ideal, but much of the potential is there, and we ought to make use of it. To capitalize on this production requires good control of hunter numbers and hunting pressure. It requires logical, sensible, and not overly restrictive hunting regulations; it requires maintaining good landowner-hunter relationships; and it requires that we authorize a full and adequate kill of deer every year.

[1] *Jenkins, D. H. The productivity and management of deer on the Edwin S. George Reserve, Michigan. 1964. (Unpublished Ph.D. thesis on file at Univ. Mich.)*

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SOME REMARKS ON YARDING DEER

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To me, the facts and figures reported for midwestern white-tails are rather astounding when contrasted to the dynamics of yarding deer in the northern Lake States. A few pertinent examples follow. Because of the bitter cold and deep snow, boreal deer normally huddle in the best shelter available to gain respite from the weather. Under such conditions, the animals promptly burn up their stored fat. They become fairly inactive in midwinter, thus conserving energy, and actually eat less browse compared to earlier in the winter. Possibly this phenomenon involves a downshifting of gears, physiologically speaking, which in some way helps the animals to stay alive. Nevertheless, many deer barely stagger out of the swamps at spring break-up, which commonly does not occur until mid-April.

Does that have been weakened by hunger produce stunted, unhealthy fawns. Following a harsh winter, we have evidence that as many as one-third to one-half of the fawns die at birth or soon after. As a result, hunters see far fewer tails flicking through the woods; hence, they are sure that all the deer are gone. Northern fawns on the average do not grow nearly as large as their southern cousins. Doe fawns rarely breed, let alone produce twins. Even the productivity of adult females is minimum — 10 to 15 percent of the yearling does are barren when the rut ends. The annual herd increment probably comes to less than 30 percent, and the actual (vs. potential) surplus is seldom if ever removed by hunting.

We consider it a good season when 1½-year-old males make up 50 percent of the legal bucks bagged. In Michigan's Upper Peninsula, the "rocking-chair" racks are grown by relatively old, tough bucks. Because of the hunter's quest for antlers, a large number of does survive to a ripe age of 10 to 15 years. The long-term prospects for northern deer are bleak indeed. With the possible exception of Wisconsin, a State blessed with many paper mills, the Lake States region is growing much more timber than is being harvested. Simply stated, more big trees mean that fewer deer can exist. A major miracle is needed to reverse the problem of serious range deterioration, but none is in sight.

DISCUSSION

Mr. Verme:

I would like to put Dr. Crawford on the spot. How, you have alluded to the fact that habitat conditions in the Midwest — and I assume you refer mainly to food and winter cover — probably will not favor deer in the future. Would you care to tell us in your judgment what might be done to retain or improve deer habitat on forested public lands.

Dr. Crawford:

Well, I think it's a matter of, first, more research - more research into what would increase the carrying capacity of these wooded lands. I assume you are talking about the marginal, submarginal type of timberlands, not about the real quality timberland, where I don't think we can do much; it probably doesn't amount to enough area to worry too much about. Basically, we need information on their food and cover needs. We need more basic information on stress caused by macro- and microclimatic factors. What do we know about cover manipulation in the nonyarding range? True, these deer do not yard, but the winter stress periods — including low temperature and winds — do affect animals. I don't think we know what we can do to manipulate the pattern to offset these climatic stresses on the animal. Basically, we don't really know what climatic stresses are, so I think we need to start out with some fairly basic research on the animal and then go from there to the habitat. We need to know how to manipulate the habitat to increase carrying capacity on the areas that we will have left for deer in the future.

Dr. Larry Jahn (Wisconsin):

I would like to direct a comment or question to Dr. Crawford. In his remarks he indicated we might be working toward a monotype environment in the agricultural region in which it is intensively utilized by people; but on the other hand we have another whole group of professional people engaged in planning. We're talking about green spans, flood plain zoning, and shoreland zoning which conceptually are vehicles for preserving habitat and diversity in the environment and the landscape itself. Do these concepts meet with your approval, or are you directly opposed to them? Do you see no hope for their application in the future? Depending upon your position, of course, you may put the planner in the position of just doing a futile job, really.

Dr. Crawford:

Well, no; I don't object to zoning proposals, but I don't see how they are going to offset a man from making a living. You say perhaps a certain area of the country will be zoned as nonagricultural. Well, this may be a little tough to sell to the man who is out there making his living from the agricultural aspects of the land. I tried to point out that the Midwestern United States is one of the most fertile areas in the world. In rough figures, 20 percent of the world's grain is produced on 5 percent of the land. Now, how this is going to affect zoning is a good question, but I think when we get into our zoning practices we'd better keep some of these factors in mind.

Dr. Jahn:

My point is that we can't resolve all these things by economics even though in your original remarks and your comments just offered you indicate that economics are the all-important vehicle for making decisions. Last night's speaker, Dr. E. S. Deevey, pointed out that there are certain things beyond the marketplace and the means of cost benefit calculations. I think that is exactly the position we are in at the present time. There are certain things that are good for society and there are good things to be done on a piece of landscape. This is why I'm pushing the point. I merely want to add another dimension to your original comments.

Dr. Crawford:

I don't necessarily say the comparison should be in dollars, but it should be in some comparative base. Granted what you say is true — there are esthetic values. Now, how do you put a dollar value on esthetics? Well, I don't think we've tried very hard in the past. I think we should try harder to develop some firm basis of comparison for arguing with a person who wants to grow corn or timber. When he says, "What does your product add to the economy," we've got to be able to tell him more than what comes from the heart. We've got to get it into more concrete terms. Perhaps you can't say a deer is worth so many dollars, but I think we'd better work for some means of concrete comparison so we *can* defend the resource that we are interested in. I don't think we have worked hard enough for this in the past. I think it is going to be much more important in the future.

Mr. Edwards (Illinois):

One of the things that has bothered me over the last few years is the fact that what we are dealing with here is a succession species. The fact is that the deer are doing best where some of the very early stages of secondary succession are best represented along with the later stages in the oak-hickory forest situation. And this simply means that if we are going to manage these species we are going to have to recognize disturbance—disturbed environments—in our management programs. And if we are going to do this we've got to recognize management measures, such as controlled burning, and some certain types of timber harvest in our management programs. We've got to come to grips with disturbance in our management, and this is about it. Until we are ready

to recognize what succession and disturbance really mean in the ecology of our species, we aren't going to make any progress in management. We've got to come back to succession management; we've got to come back to listen to what other people like Wallace Grange really had to tell us 20 years ago.

Mr. Murphy:

I think this is what I was really referring to when I said that if we are going to give the deer the help they need to meet the growing demand for them, we are going to have to get more specific in our management recommendations. All of these management recommendations, however, come back to the need for research. In other words, you say burn — what time of the year do you burn, under what conditions do you burn, in what habitat do you burn, what results do you get from this burn? Burning is merely one tool, but we need the research. We're fighting this now in Missouri. We're buying land, and the men on the management staff are coming and saying, "What practice can we apply on this land? If we do such and such — what happens?" Well, we're getting the cart before the horse. Instead of putting $80,000 into management, we should put it into research to get the answer before we act.

Dr. Gross (Colorado):

I'm unfamiliar with your deer management practices and research activities in this area, but I would like to direct a question to anyone on the panel. Has anyone been able to place a quantitative relationship between deer densities and browse availability below that point where deer starvation sets in? We've spent many millions of dollars on browse surveys, carrying capacities, and so forth. Have we in any single instance yet gotten to the point that we can equate deer densities with browse availability below that point where a catastrophe occurs? Has anyone been able to say that a given range will carry 235 deer per square mile, or 14 deer per square mile, below that point where some very serious occurrence happens to the herd?

Mr. Murphy:

We went this direction in the forage survey which I mentioned briefly. This was an extensive survey of understory vegetation on National Forest lands in Missouri. There are about 2 million acres. We spent an entire summer with a field crew measuring the understory vegetation. We've determined the pounds per acre of available deer forage for the summer and for the winter. From this we have calculated the carrying capacity for this land. In the black-scarlet oak forest type which covers the majority of the land area, it's only three to five deer per square mile in the winter time. And this in many areas is at carrying capacity at the present time. In most forest types, it was less than eight deer per square mile. The deer are not in excess on any of this land at the present time, and range deterioration is not occurring because we harvest them annually on an any-deer basis. Does this answer your question? Is that what you were looking for?

Dr. Gross:

More or less. The point is, has this really been proved? Would this range carry eight deer per square mile?

Mr. Murphy:

All right. Let's take another example of Hew Crawford's work in Arkansas. They established two 1-square-mile enclosures. They shot out the deer entirely, then restocked at known levels and have censused these deer annually. Browse production surveys indicated that those areas could carry eight deer per square mile. All right, they had a couple of years of good acorn crops, and the herd increased to above eight (perhaps 12 to 15) deer per square mile. Then came a year of acorn failure and they died back to eight per square mile.

Dr. Crawford:

It wasn't just a browse survey — this is the important point. This was all vegetation available for deer during winter. Now, the Ozarks probably have had more food habits work done than, I suppose, any other region of the country. So we knew pretty well what they were eating. It wasn't just browse, but the plants that were known to be deer food — not the oak sprouts, not the hickory sprouts — but the food plants. I think this is one of the keys. I know there have been a lot of browse surveys made, and everybody has assumed that deer eat browse. We're doing some food habits work in the Southeast now, and we haven't found many woody twigs utilized during winter — spring, yes — but during winter there may be one or two instances of hardened woody twigs being browsed.

Dr. Jenkins:

It's almost predictable that when researchers and deer managers get together the deer managers will say we need some research to indicate to us what will happen if we treat a piece of land in a certain way. Have either the researchers or the managers ever sat down and tried to work out the various combinations — the astronomical number of combinations of factors that are working on a piece of land that determine what happens if you do this or that? They say, now, if you take a swamp edge and cut it over *this* way, this will happen. In a pig's ear it will! It might happen sometime, but it isn't going to happen that way all the time. We'll be lucky if it responds that way 10 percent of the time. I wonder if the time will ever come when we can develop a good way to measure habitat. Sure, we can do it at the research level, but how do you do it statewide? How do you turn it over

to all the district men and have them all working on the range measurements? They'd never do anything else. When would they do the prairie chicken dancing surveys and other things they have to do that are absolutely important? So we come up with another way to look at this. Perhaps we can put a "computer" out in the woods and feed all the information into that computer and then have it feed back the answers as to what the range conditions are. You know what the computer is — a deer. He takes all the data — all the known climatic data and all the range factors and snow depth and everything else — and he puts them through his computer and he comes up with a certain physiological condition. Now we have to learn to measure those factors. Once we can learn to measure the deer and get the information out of him, we might be able to come to this point where we say we are carrying just enough deer or we are carrying too few deer. It is very difficult to measure range conditions — and do it on a practical basis so you can do it in the spring of the year before you set your hunting regulations. That's the practical end of the thing.

Mr. Verme:

I would like to make a comment in addition to what Dave has said. Part of our problem, at least in the far north, is that we don't really understand what motivates this animal — what he's responding to. Deer, even in our winter yards, are not uniformly distributed throughout the area. There are pockets, little niches that supply exactly what they are seeking. We can go through a swamp and possibly make a browse analysis survey to determine the carrying capacity, and we find that on the average, a swamp may be in pretty good food condition and yet where the deer are, they are starving. Perhaps this doesn't apply quite as rigidly in the Midwest, but I think it's important to try to understand this animal before we run out and make browse surveys or try to do some habitat improvement programs. It won't always work because the deer just don't follow in the same directions.

Dr. McCollough (University of Michigan):

I agree with Dave about the difficulties here and it's sort of the Harvard Law of animal behavior — under carefully controlled conditions, deer behave as they damn well please. On the other hand, if we take this approach I'm sure we're closing some potential doors. In other words, if we assume that the variables are so great that we can't possibly measure them, we aren't going to try. At Michigan we *are* trying certain things. Now, not all species are equally good deer food, and there are things known as ice cream species which have potentials of indicating the capacity of the land in relation to the current density of deer. And there is a possibility of modeling systems using this sort of species. Now, I would just like to point out first of all that tomorrow there will be a talk by Dennis Kuck who is working on [illegible] attempting to do the [illegible] hasn't worked out as well as it could [illegible] some qualifying factors, too.

Now on the George Reserve [illegible] are going this way: we can follow the deer population very precisely and we're looking [illegible] environment — in the habitat — for certain species which will reflect what's going on so that we can find this series of species that will [illegible] level: some that are very immune to [illegible] that are very sensitive. A combination of [illegible] ments on these species might reflect exactly what's going on.

Now I want to add a little bit to the [illegible] this system myself by commenting on the fawn weights given by Dean Murphy earlier. Fawn weights are really not only related to fertility of soils: the factor of density has to be taken into account. On the George Reserve I'm sure we could produce fawns to about 70 or 80 pounds, and we can produce them up to 100 pounds, depending on the density of deer we keep on the area. This brings another point into focus and that is we talk about carrying capacity as if it were one thing. As a matter of fact, there's a whole range of potential carrying capacities, depending on what you want to accomplish and what sort of changes in vegetation you are willing to accept. If you don't want *any* species on the area damaged, you're talking about a carrying capacity that is zero. Some plant species go out as soon as a deer comes in. But you have to make some sort of judgment as to what you are willing to sacrifice. In terms of the George Reserve, you can say there is one carrying capacity that gives the optimum harvest. There is another carrying capacity that can be maintained over a sustained period of time if you are willing to give up some of the fawn crops. But you can maintain a standing crop, i.e., the existing biomass, out there very well. So the carrying capacity of the George Reserve might be anyplace between 60 and 120 animals, but you have to make up your mind what you mean by carrying capacity.

Mr. Nixon:

There has been a good bit of talk in the last 15 to 20 minutes about carrying capacity as it relates to the woody hardwood cover or range of the deer. We tend to think of them as farm animals. In Ohio when we talk about carrying capacities there are two other areas that desperately need research — crop damage and highway kills. We've got areas in northeast Ohio today that could support far more deer than they do, yet we can't stockpile them. We lose them just as fast as they are produced, on the highways. We know very little about what motivates deer to cross roads,

how to keep them off roads, how to keep them out of orchards and other crop areas once these patterns are established. Yet, when you talk about carrying capacity, in much of the agricultural range you are talking about agricultural crops. This is the carrying capacity as far as food habits. The wooded range functions primarily as daytime cover, not food. And in order to approach a reasonable carrying capacity in terms of harvest, we need to do something to mitigate these other losses.

Dr. Cowan (Michigan):

I have a couple of comments. Hew, I've seen white-tails in South Dakota where you have to travel an awful long way to find any woody cover at all. I'm wondering whether your pessimistic view of the ultimate demise of our woody cover through the Midwest necessarily means disappearance totally of the white-tail from the area. Also, I would like to find out from Dave what ideas he may have for getting to the regulations he says we should have in order to manage these farmland deer.

Dr. Crawford:

I'm not familiar with the situation in South Dakota, but I would guess two factors affect their ability to support deer herds. First, perhaps some of the hilly areas are important; this has some influence when you compare it with our flat table lands in the central Midwest. Secondly, aren't those white-tails in South Dakota pretty much related to the draws that are somewhat brushy, and isn't woody cover a part of their environment? If woody cover isn't important I'll be surprised, because work done in Iowa and Kansas has shown that it is quite important. The areas where they have deer are areas where they have woody cover. Another thing, I don't think it will just be cover. I think in the future it could very well be food. As I mentioned, right now there is a lot of crop wastage and plenty for the deer to eat through the winter — corn spillage and soy beans. But I think future technology will increase the efficiency of harvesting. I don't think you'll get as much crop loss in the future as we have now — it's substantial now. More efficient harvesting will be another way for the landowner to make money and, judging from what agricultural research has done in the past, I'm sure harvesting will be improved in the future. So food may be a problem also. Time will tell.

Dr. Cowan:

I think that you will probably find that the farmer will be a greater determinant in such an intensive situation than the actual availability of cover or food will be.

Dr. Crawford:

I think the farmer will be very important in the future. Whether he wants deer or not will determine whether we have deer or not, and if he can realize some return from having deer I think that's going to increase the likelihood that we will have deer in the future.

Mr. Verme:

Arch, I think you are meaning to say, or ask the question, do deer really need cover in the Dakotas for winter survival? Now, that brings up a point. Moen, in a recent issue of *Ecology* and in *The Journal of Wildlife Management,* brought up the same question; and he claims that despite a tremendous amount of heat loss, say in western Minnesota, the deer didn't seem to mind the bitter cold and got along and fed actively at night when the heat loss was quite severe. But this is only where they have excellent farm crop foods available. They have to take in more energy than they are losing. In areas where this nutritious food is not available, I would think — without knowing too much about the western conditions — that cover is highly essential for white-tails. The farther south you go, of course, the less important it is.

Dr. Cowan:

This is what you've been talking about — the most fertile farmland in the country.

Mr. Verme:

Well, it may or may not be fertile or the food may not be available during mid-winter under this 2 to 3 feet of snow. Then what will the animal do? He has to conserve energy in some manner to stay alive, and cover is important.

Dr. Jenkins:

What can we do — what practical hunting regulations should we have? Well, first of all, every square mile, every square millimeter, of southern Michigan, of southern anything else should be open to deer hunting to provide the greatest hunting opportunity where the landowner will permit it, of course. No deer should be illegal, and the kill should be controlled by controlling the number of hunters. Where you have large numbers of hunters, they should be properly distributed by some type of a system. Now, where you only have few hunters it doesn't make much difference. We ought to head for a harvest of about half antlered and half antlerless deer. We ought to head for sensible firearms regulations. My home State of Pennsylvania, up until recent years, did not permit buckshot to be used. It was an abomination; it was horrible; it was sinful, you see. Right across the river, in New Jersey, you couldn't even use a rifled slug. It was sinful; it was horrible! I think we ought to head for a type of hunting regulation that is effective and sensible. I think this muzzle-loader business is coming right along. Our reason for sticking to shotguns is not real good. It's a real uphill battle to convince the County Board of Supervisors that they should permit the use of rifles. But I think this

would improve the sport, and interest in it, if rifles were allowed. We'll have to say we're not going to have deer populations above a certain level because of certain practical reasons, such as crop damage and automobile damage. But the main thing is to have as liberal hunting regulations as possible, with all areas open but with the distribution and size of the kill controlled. Some type of a permit system may be necessary, as we mentioned. And we ought to aim for a 50:50 antlered-antlerless ratio, not a 90:10 ratio.

Dr. Jahn:

I don't know what sections of South Dakota Arch was referring to, but there are some sections in that type in winter in which wetland habitat functions as a woodlot and serves as excellent cover for white-tailed deer; beds are abundant and the animals are found there. Similarly, in southern Wisconsin large marsh areas of wetland habitat — emergent wetland vegetation — serve as excellent cover. Deer do survive, and it becomes in effect an anchor within their home range for bedding purposes, by and large, or escape cover. Also, the stress seems to be on the parts of woody cover within this agricultural block of this country. Does anyone on the panel know if any of these States have some sort of a program for woodlot preservation? If so, what are the mechanisms for maintaining privately owned woodlots?

Dr. Crawford:

Probably someone else could answer this better than I, but there are standard ACP payments for practices conducted on woodlands and other economic inducements. I don't know if this is strictly for woodlot preservation. It's managed by and large under ACP. I'm speaking of preservation or maintenance of, say, 20- or 40-acre blocks of woodland. There is a fairly strong force called farm foresters who are very enthusiastic about the resource they work on, and I imagine they are rather influential. But as far as a formal program goes, I don't know.

Mr. Nixon:

Ohio has a law on the books whereby they get a tax credit write-off for woodlot preservation, but unfortunately the tax assessor will take it off a woodlot and put it on somewhere else. So really there's no attempt made to save the woods, and in western Ohio we are losing it fast.

Dr. Jahn:

That same thing with the tax write-off and differential assessment is an old law in Wisconsin. You are absolutely right — the assessor makes the adjustment and puts the increased rider on the remaining taxed property.

Mr. Hallam (Virginia):

I noticed that most States harvest their bucks at such a high rate that few reach a very old age. I wonder if Dr. [illegible] feels there is [illegible] public lands.

Dr. Jahn:

You develop trophies [illegible] have to live for [illegible] feed their life [illegible] in, say, 2½ years. When you start talking about [illegible] to 400 thousand deer hunters [illegible] that in this country [illegible] shortly come to see the [illegible] trophies under those conditions [illegible] area inaccessible to hunters [illegible] hunter can get anyplace. So I think that the [illegible] trophy hunting — or quality hunting if you will — is something that we cannot look forward to in heavily hunted States. I think the trophy hunter [illegible] have to look someplace else. Now [illegible] certain areas for light hunting, but there are too many things that affect deer numbers that we [illegible] here before. A deer is a creature of the early stages of succession, and as the land changes [illegible] lands of animals that live there change [illegible] great truth. And so as the land grows up [illegible] to carry fewer and fewer deer. Deer [illegible] within limits of their food supply [illegible] trouble. The idea of restricting hunting [illegible] places in order to create trophy [illegible] else. Now it may well be in the farmland country that a 2½-year-old deer is a trophy deer [illegible] good looking deer. Once the [illegible] of antler size [illegible] it's not too hard to have [illegible] old in some of the areas where there [illegible] vate land. But the chances are [illegible] There are more and more people and there is more and more accessibility. Of course, what [illegible] to my grandfather and what is a trophy to me are two different things, you see, we have that [illegible] too; but I'm not optimistic about trophy hunting [illegible] am I optimistic about whether you could set an [illegible] aside and restrict the kill of deer [illegible] or restrict [illegible] accessibility — which is restricting [illegible] create trophy hunting. Maybe somebody might have a different idea, but if he has I'm always glad to hear how he's going to work it out. [illegible] vore and therefore his own worst enemy.

Dr. McCullough:

I don't have a question but I do have a comment on this past question. I don't think there's a population in the country that has been shot as h[illegible] the George Reserve population over [illegible] that in many years, and we have at least six [illegible] out of a hundred out there that any [illegible] in this room would be proud to have on his wall. I don't think you really [illegible]

shooting. You may reduce the number of them, but certainly they are out there, and it takes a darned good hunter to get them.

Dr. Jenkins:

I won't argue, Dale. It just depends on what you call a trophy. What I was calling trophy is one that would qualify for the Boone and Crockett Club. I agree that there are some nice deer running around in southern Michigan and on the George Reserve that make good trophies, but it all depends on what you call a trophy. If you want a Boone and Crockett Club record, they aren't on the George Reserve, Dale. Having been an official scorer for a couple of years, I believe that unless a rack is as big as a bushel basket there is no point in wasting time measuring.

SUMMARY

LOUIS J. VERME

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A brief resume is in order to wrap up this stimulating symposium. Generally, the picture for midwestern white-tails is fairly bright, at least during the next few years. A herd numbering 1 million animals by the early 1970's is a mighty impressive total. Beyond the next decade, however, the situation evidently may take a sharp downturn locally, if not more extensively. Due to expanding human population, suburbia will continue to encroach on what presently is good deer range. Changing economics probably will dictate that relatively fertile farmland be utilized intensively for agricultural crops, almost to the point of excluding deer in the Corn Belt. Woodlots may be overcut or improperly cut, thus eliminating essential cover for deer. In some instances the woodlands will be converted to grassland to grow livestock. On the other hand, some currently submarginal acreage is actually reverting to lush deer habitat, as is now the case in southern Michigan, for example.

High human densities and deer are surprisingly compatible. But when the situation becomes seriously imbalanced, deer obviously must give ground. Chances are that incidental mortality of deer from such things as automobile collisions, poaching, and free-running dogs will continue to worsen. To prevent such waste of venison, the legal harvest must be maintained as high as possible, closely exploiting the great reproductive potential of well-fed does. We seem to be headed in the right direction in this regard, even if not fast enough or in unison.

Apparently, henceforth we will have to manage more intensively on steadily diminishing deer range, working with land of poorer carrying capacity as well. Do we have the necessary knowledge, incentive, or support to accomplish the job? We probably can do little to alter the strong socioeconomic pressures and and changing living patterns. However, it seems doubtful that we know enough about the basic biology, ecology, and behavioral aspects of deer to make the most of this resource. So far we have been managing deer by the "seat-of-our-pants," and fortunately getting away with it. I fully concur with Dean Murphy that we must develop game management from the art that it has been to a precise science.

This symposium logically serves as a focal point for documenting available information about midwestern white-tails. But it also emphasizes our shortcomings in terms of what we ought to know and where we are headed. Clearly, we are being challenged to better manage our fine deer herds in the midwestern farmbelt. From all indications, the prospects for success are encouraging.

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Prescribed Burning Weather in Minnesota, by Rodney W. Sando. USDA Forest Serv. Res. Pap. NC-28, 8 p., illus. 1969.

Durable Rustic Wooden Signboards, by Glenn A. Cooper. USDA Forest Serv. Res. Pap. NC-29, 15 p., illus. 1969.

The Market for Wood Picnic Structures, by Jerry A. Sesco. USDA Forest Serv. Res. Pap. NC-30, 7 p., illus. 1969.

Oak Forests of the Lake States and Their Management, by John L. Arend and Harold F. Scholz. USDA Forest Serv. Res. Pap. NC-31, 36 p., illus. 1969.

Wildlife Esthetics & Auto Campers in the Superior National Forest, by David W. Lime and Charles T. Cushwa. USDA Forest Serv. Res. Pap. NC-32, 8 p., illus. 1969.

Standing Timber Coefficients for Indiana Walnut Log Production, by James E. Blyth, Edwin Kallio, and John C. Callahan. USDA Forest Serv. Res. Pap. NC-33, 9 p., illus. 1969.

Climatic Conditions Preceding Historically Great Fires in the North Central Region, by Donald A. Haines and Rodney W. Sando. USDA Forest Serv. Res. Pap. NC-34, 19 p., illus. 1969.

Initial Thinning in Red Pine Plantations, by John H. Cooley. USDA Forest Serv. Res. Pap. NC-35, 6 p., illus. 1969.

Biological Growth Functions Describe Published Site Index Curves for Lake States Timber Species, by Allen L. Lundgren and William A. Dolid. USDA Forest Serv. Res. Pap. NC-36, 9 p., illus. 1970.

Defect Indicators in Sugar Maple — A Photographic Guide, by Richard M. Marden and Charles L. Stayton. USDA Forest Serv. Res. Pap. NC-37, 29 p., illus. 1970.

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The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

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SEARCH PAPER NC-40

TREE IMPROVEMENT OPPORTUNITIES in the NORTH CENTRAL STATES as RELATED to ECONOMIC TRENDS,

A Problem Analysis

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DEC 2
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U.S. DEPARTMENT OF AGRICULTURE

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The original draft of the manuscript was presented at the Program Review at the Institute of Forest Genetics at Rhinelander, Wisconsin, on April 24, 1969. Many helpful suggestions presented by representatives of the universities, industry, and State and Federal Government in the North-Central Region were considered in preparing the final draft.

Although the authors accept full responsibility for the findings of the survey, and the recommendations presented, they are none-the-less grateful for the help of all the reviewers.

Tree Improvement Opportunities in the North-Central States Related to Economic Trends

David H. Dawson and John A. Pitcher

Abstract

The National need for wood products is expected to increase 80 percent by the year 2000 and there is estimated continued growth in demand after 2000. These products must be grown on a constantly diminishing area due to increased use of land for other purposes.

Tree improvement is one possibility for increasing quantity and quality of forest products in the North-Central Region.

Priorities for tree improvement programs can be determined by analysis of (1) the projected demand for forest products for the year 2000, (2) the nature and availability of planting sites, (3) the forest management alternatives to meet the demands, and (4) the amount of genetic guidelines available.

Based on an analysis of these factors, the major emphasis on regional tree improvement programs should look first toward increased yields of fiber (woodpulp) and second toward better hardwood veneer. There is little indication that the lumber industry will grow significantly.

Until more basic genetic information becomes available, developmental and action programs in tree improvement in the Region should concentrate on the following (listed alphbetically):

Betula alleghaniensis
Juglans nigra
Larix spp.
Picea glauca
Picea mariana
Pinus banksiana
Pinus echinata
Pinus strobus
Pinus resinosa
Populus spp.

The "North-Central Region"—Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, and Missouri — is about 28 percent forested. This 76-million-acre natural resource contributes substantially to the economic and social well-being of the people within and beyond the Region's boundaries. In 1962, the North-Central Region produced over one billion board feet of saw logs, 96 million board feet of veneer logs, and over 3 million cords of pulpwood. In 1958 timber-based economic activity, including the conversion of imported wood products, added over 4 billion dollars to the Region's gross product (Hair 1963).

Because of the importance of this resource, much attention has been and will be given by public agencies and private industry to maintaining and increasing the quality and quantity of forest products.

The productivity of forest land and the quality of forest products can be increased by various forestry practices, singly or in combination. One of these practices is the use of genetically improved planting stock in reforestation, which suggests the needs and possibilities for applied research, developmental, and action programs in forest tree improvement.

The purposes of this problem analysis are (1) to determine how tree improvement programs can best help satisfy the large increases in demand that will be made on the forests of the North-Central Region, (2) to set general species priorities, (3) to establish a method of analyzing tree-improvement program needs, and (4) to suggest specific improvement programs for priority species.

While certain portions of this problem can be quantified, the scope of this present analysis is confined to the qualitative aspects of the total problem.

From the standpoint of discussion, administration, and analysis, it seems necessary to place precise definitions on "tree improvement" and "forest genetics." In reality the two fields are almost inseparable at this time.

"Forest genetics" is the broad field concerning variation and inheritance in forest trees. Although this analysis is not intended to explore the needs for forest genetics research, it may possibly serve to orient basic forest genetics programs.

"Tree improvement" refers to the application of forest genetics to bring about heritable improvement in trees (Dorman 1962). It involves:

1. Selection of superior trees for growth rate, form, insect, disease resistance, etc.
2. Planning and establishing seed-production areas.
3. Planning and developing clonal and seedling seed orchards.
4. Open and controlled pollinations to determine general and specific combining ability.
5. Mass production of improved species, hybrids, or other variants.
6. Small seed-source studies to determine best sources for local use.

This publication does not contain a review of literature pertinent to forest genetics, tree improvement, or the economic and social aspects of forestry. It refers briefly to the more significant works in these fields as they relate to the possibilities for tree improvement in the North-Central Region.

Although the need for improved trees for aesthetics or special purposes such as air purification, erosion control, shelterbelts, or the production of timber-related crops (e.g., Christmas trees) is recognized, these needs are beyond the scope of this study.

Tree-improvement is by necessity a long-term effort. It is essential, therefore, in program planning to consider the needs and nature of future society and its probable technological development at the time the products of today's projects are available.

Projects being started today are not likely to be producing many tested, improved materials much before the year 2000. The tree breeder must consider not only which *species* will be needed to meet the demands of the 21st century, but also what *specific traits* within the species may become most important. He must consider the amount of suitable land available for planting improved trees and what intensive cultural practices will be used to take advantage of the improved biological efficiency of the tree.

What, specifically, will be the demands of the 21st century? What will be the effects of population pressures on land use? What specific forest products will be in the greatest demand? These questions are difficult to answer. Nonetheless, it is generally agreed that the demand for all timber products, with the possible exception of fuel wood, will increase.

Any plans based on long-term projections and estimates of future situations must be flexible. Forest genetics researchers will continually develop new variants of species, new hybrids, and new introductions. As we learn more of the genetic potential of various genera and species, more alternatives will be available to the tree-improvement forester. Similarly, as changes occur in industrial technology in the wood-using industries, in economic projections, in the development of substitute materials for wood, or in new wood products, the plans for tree-improvement programs may change also. There will, therefore, be the need for periodic reviews of the problems and revision of the programs discussed in this analysis.

Because of the diverse objectives and product requirements of the various agencies and industries interested in tree improvement, it is impossible to set specific, inflexible priorities for species improvement. However, the analysis of problem components and presentation of alternate solutions should help each interested organization or agency more effectively set its own more precise priorities within the "high priority" group presented here.

The Problem

This study addresses itself to a component of a more extensive National problem cited by numerous other investigators (USDA Forest Service 1965; Hair 1967; Landsburg *et al.* 1962) and briefly summarized by Cliff:[1]

> "Demand for timber products in domestic and export markets has been growing steadily, and we foresee very substantial further increases in the years ahead.
>
> "At the present time our expanding markets for timber products are being supplied by young-growth forests, particularly in the East, by liquidation of old-growth stands in the West, and by importation of about 10 percent of our total wood use.
>
> "In the near future, however, our forests – under present levels of management – will be unable to supply prospective increases in timber demands. The supply of timber prospectively available from domestic forests and probable imports begins to fall short of the rising trends in use within the next 15 to 20 years. By the year 2000 the projected supplies will fall considerably short of the Nation's projected demands for timber."

and

> "The most promising opportunities for meeting the large increase in future demands for timber products are to be found in intensification of management of our public and private forests. In all forest regions supplies of timber could be substantially increased by such measures as planting, thinning, stand improvement, increased protection against destructive agents and access road construction."

and

> "–silvicultural measures such as tree improvement and use of fertilizers also show great promise for increasing timber growth and quality."

To decide what species or what specific improvement objective within a species will offer the best opportunity for increasing the growth and quality of forests in the North-Central Region four factors have been seriously considered:

1. *The projected demand for forest products.* – Projections of demands indicate general trends in products usage. Although no projections can be completely accurate, they certainly serve as a better guide to the future demand than do the demands of the present. The major forest products considered are pulpwood, plywood and veneer, and lumber.

2. *The area and condition of the Region's commercial forest land.* – We need to ascertain the quality and quantity of land that will be available to provide optimum planting sites for improved trees. By analyzing timber type data it is possible to estimate acreages of land with alternative possibilities for treatment and thus develop some guidelines that will indicate tree-improvement programs needed to satisfy projected demands.

3. *The consideration of other alternatives to meet the demands for the products.* – Although tree-improvement programs may be used to meet future demands, other alternatives may be more economical, more rapid, or more effective. These alternatives need to be considered in any forest management decisions and in particular where long range investments are contemplated.

4. *The status of genetic knowledge available to breed trees.* – The amount of basic genetics information available for various species or genera is essential in determining if they are to be emphasized in a tree-improvement program. It is not economically or technically feasible to initiate tree improvment without *some* knowledge of heritabilities for specific traits. Developmental and action programs can be much more effective if they are based on proven genetic factors.

In the following sections these four factors are discussed.

Projected Demands for Forest Products

An appraisal of the demand for forest products exclusively on a regional basis is not realistic. No longer can the North-Central Region be considered an entity and the situation evaluated from a standpoint of balancing regional supplies and demands. Indeed, Zivnuska (1967) reported

" . . . there is a need for a reassessment of the importance of present and prospective *international* developments to evaluations of the timber resources of the United States."

The demands on the forests of the Nation as they relate to both domestic and international needs must be considered first in this study. The role that tree improvement can play in contributing to the production and quality of forest trees in the Region will be considered within that framework.

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1 *Cliff, Edward P. Wood needs of the future and how they will be met. Statement before Subcomm. on Retail, Distrib., Market. Pract. of Select Comm. on Small Bus., U.S. Senate, Nov. 26, 1968.*

The Timber Trends Report

The current and projected demands on the Nation's timber supply are well analyzed in *Timber Trends in the United States* (USDA Forest Service 1965a). In summary the report reached the following conclusions:

1. Demands for timber products are projected to increase about 80 percent by the year 2000. To meet these projected demands for roundwood, the cut of sawtimber in the Nation's forest, after allowances for imports, is estimated to rise from 48.4 billion board feet in 1962 to 81 billion board feet in 2000.
2. Population is assumed to rise from 187 million in 1962 to 325 million by 2000 — a 74 percent increase.
3. Continued technological improvements in production and marketing in the forest industries will be essential to achieve projected demands for timber.
4. Imports of timber products are likely to increase somewhat, but most of the timber required to supply future U.S. markets is expected to come from domestic forests. Some increases in net imports of lumber and pulpwood products are expected, mainly from Canada, which has extensive undeveloped softwood timber resources.
5. Prospective timber growth and inventories in the U.S. under current levels of forest management *appear sufficient to meet projected demands for the next two or three decades, but not for the later years of this century*. By 1990 projected supplies of sawtimber approximately equal the projected cut but fall short of the projected cut by about 16 percent, or roughly 13 billion board feet, by the turn of the century.
6. Declining quality of timber resources represents a major problem for wood-using industries. Only a part of the total volume of timber growth and inventories is economically suitable raw material. Further reductions in tree size and quality are to be expected if timber cut and growth follow the projections and management continues at recent levels.
7. The outlook is favorable for the pulp and paper industry, but not as encouraging for the the lumber and plywood industries. In recent years, the pulp and paper industry has greatly increased its use of hardwoods. Use of chips from sawmill and plywood plant residues has risen even more sharply.

For the lumber and plywood industries, the timber supply situation in most regions is much less favorable. The adequacy of raw material supplies for these industries does not depend on the total inventory of fiber, but rather on the operable supply of wood of desirable quality and size.

Other Projections

All projections are not as optimistic as those of *Timber Trends.*

Hair (1967) presented alternative ways of projecting long-run trends in demands for paper and board. His projections for pulpwood in 1985 are about 44 percent above those in the Forest Service report. Given this much increase in the cut of pulpwood, and assuming the cut of other timber products and levels of forest management would be about the same as stated in the *Timber Trends* study, projected timber supplies would fall far short of the total timber demanded around 1980. This prospective imbalance, along with declines in the size and quality of harvested trees, points to an increase in the competition for timber and concurrent increases in production and marketing costs beyond the levels that appeared likely in the *Timber Trends* analysis.

Hilliker[2] reported that the most recent projections of future wood requirements indicate total consumption of timber may increase by about 76 percent by the year 2000. However, the major wood products will not share equally in this growth, nor will the major timber-producing regions. A continuing decline in per capita consumption of lumber is expected, with total consumption approximating present consumption. Hardwood plywood and veneer consumption could increase 300 to 400 percent over the next 30 years, but imports and synthetics will control the larger share of the market. He reported pulpwood consumption in the year 2000 could reach two or three times the current level, increasing to 50 prcent or more of total industrial roundwood consumption.

Of greatest significance in these later projections is the greatly reduced estimate of projected lumber consumption and larger increases in demands for veneer, plywood, and pulpwood when compared to the earlier projections in the *Timber Trends* study.

Table 1 summarizes the projections for National consumption, allowable cut, and deficit between cut and consumption. *This deficit reflects the amount by which roundwood production must be increased by intensified forest man-*

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2 *Hilliker, Richard L. Projecting future trends for Lake States timber. 1969. (Unpublished Ph.D. thesis on file at Univ. Wis., Madison.)*

Table 1.—*Domestic consumption of timber in the United States, 1962, with projections to 1980 and 2000 for consumption, cut and deficit*[1]
(Billion cubic feet, roundwood equivalent)

Timber product	Consumption			Cut	Deficit
	1962	1980	2000	2000	2000
Lumber	2/ 5.9	6.9	8.4	6.9	1.5
Softwood	2/ 4.7	5.5	6.6	5.5	1.1
Hardwood	2/ 1.2	1.4	1.8	1.4	.4
Veneer and plywood	2/ 1.0	1.8	2.6	2.0	.6
Softwood	2/ .8	1.4	2.0	1.6	.4
Hardwood	2/ .2	.4	.6	.4	.2
Pulpwood	2/ 3.3	5.4	3/ 13.2	7.4	3/ 5.8
Softwood	2/ 2.3	3.6	7.9	4.4	3.5
Hardwood	2/ 1.0	1.8	5.3	3.0	2.3
Other	2/ .5	.5	.5	.3	.2
Softwood	2/ .3	.3	.3	.2	.1
Hardwood	2/ .2	.2	.2	.1	.1
Total	2/ 10.7	14.6	24.7	16.6	8.1
Softwood	2/ 8.1	10.8	16.8	11.7	5.1
Hardwood	2/ 2.6	3.8	7.9	4.9	3.0

1/ Source: USDA Forest Service (1965).
2/ Estimated.
3/ Based on projection by Hair (1967) of 1985 demand for pulpwood to be 44 percent above projections of Timber Trends.

agement, including tree improvement, if demands are to be met.

What demands will be made on the forests of North-Central Region to supply the major wood products — pulpwood, plywood and veneer, and lumber? Although changes in technology may bring about new demands for forest products and entirely new types of industries in the Region, the future needs of *today's* industries must be considered in planning the source of supply for the future. Changes within the industry can at least be estimated. Considering the investment that various industries now have in the Region, it seems reasonable to plan long-range programs to supply the same type of end product — pulpwood, plywood and veneer, and lumber — rather than speculate as to what new industries may locate in the Region. It would be feasible, for example, for a sulfate pulpmill to change its major species from aspen to spruce, if spruce were available in larger supply and at a more favorable price; it would not likely be as economically feasible for a sawmill to convert to a fiber mill.

Pulpwood

In 1966 about a tenth of the paper-making capacity of the United States was located within the North-Central Region (USDA Forest Service 1965b, Blyth 1966). Sixty-two of the plants produced a daily total of 11,015 tons of wood pulp (Blyth 1967).

Forty-eight of the mills, producing over 9000 tons of pulp daily, are located in the three Lake States; half of this capacity is in Wisconsin. The remaining 14 pulp and paper plants are in the States of Iowa, Illinois, Indiana, and Missouri. Their capacity is about 1,500 tons per day; of this, Illinois contains over half.

Recent expansions in the paper industry nationally have been in the South because of the rapid growth of its forests and its ample water and labor supply. However, the industry is rapidly using up remaining potential mill sites and swiftly closing the gap between available annual growth and the demands of the future. Also, the rapidly expanding use of southern pine logs for plywood, is creating some local competition for roundwood (Hair and Ulrich 1969). As this happens expansion in the Lake States becomes more likely (Casey).[3]

Expansion of the pulp industry in the Lake States has, indeed, started. Actual and potential publicized mill construction and expansions indicate a rise in the area pulping capabilities of 10 percent between 1966 and 1970. In the Central States for the same period, plans for only one new mill have been announced. However, three new mills proposed for Kentucky will receive much wood from Indiana, Illinois, and Missouri (Blyth 1967). There are five major types of wood pulp used in the manufacture of paper and board; they show widely divergent trends in national consumption. These trends are evident in the North-Central Region. The increased use of sulfate and semichemical pulping processes give the pulp and paper industry greater leeway in

3 *Casey, Samuel A. The pulp and paper industry; a dynamic force in the National economy. Address to Wis.-Mich. Chap. Soc. Amer. Forest., February 1968.*

selecting species. The sulfite process which is declining in importance in the Region, depends almost entirely on spruce, tamarack, and balsam. At least two sulfite mills in the Lake States have recently closed to be replaced with kraft facilities (Blyth 1967).

The use of spruce is declining because it is in short supply and can be substituted by other species in the sulfate and semichemical pulpmills (fig. 1). The use of jack pine, on the other hand, has risen since it is available in quantity and is used largely in the sulfate process.

Also, the use of aspen has risen tremendously. In 1965 Lake States mills used more than 2.3 times the amount consumed in 1946. Aspen is pulped mainly by the semichemical and the sulfate process.

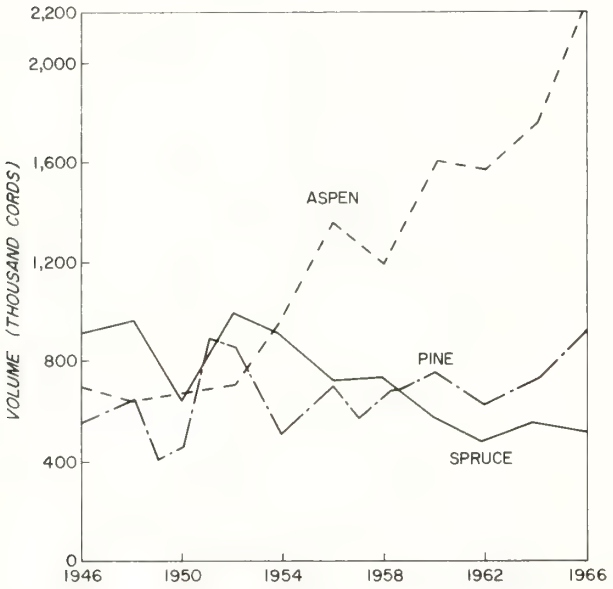

Figure 1.—The trend in use of aspen, pine, and spruce pulpwood in the Lake States, 1946-1966. (Sources: Horn 1965, Blyth 1966, 1967)

It is significant that the use of tamarack is increasing. The rather sudden interest in this species may reflect recognition of its high density and good yields using the kraft (sulfate) process. It is heavier than jack pine and yields as much as 20 percent more fiber. Tamarack yield also compares favorably with hamlock, balsam fir, and spruce under similar pulping conditions (Blyth 1968a, USDA Forest Service 1964).

Other species commonly used are balsam fir, birch, white and red pine, and mixed hardwoods. The industry needs species of various characteristics to manufacture the many grades and qualities of pulp necessary to supply the markets.

Anticipated Production Trends in the Region's Pulp Industry

The pulp and paper industry is recognizing the need to develop new concepts of fiber production. It accepts that it must concentrate its fiber production on fewer acres. Because of the adverse tax structure of most States and increasing harvesting costs, it is increasingly more difficult to profitably hold land for the length of rotation. These long, 30-year-or-more rotations added to the unfavorable tax situation do not attract investors. The treatment of capital gains from timber growing is also becoming more restrictive (Casey).[3]

Rising transportation costs tend to discourage continued large scale imports from Canada and the West.

A short-rotation, highly intensive management system using specially bred varieties and hybrids of trees adaptable to specific sites is under study by various companies and agencies (Westell 1969, Larson and Gordon 1969).

There is a need to use all the wood cut. Perhaps as much as 50 percent of the cellulose produced by the tree is wasted in present logging methods.

Finally, equipment that will mechanize the wood harvesting system is needed and is in the process of development (Gabriel 1968).

Regardless of the silvicultural systems that may come into practice, the pulp manufacturer will require large quantities of timber possessing the following characteristics:

1. High yield of fiber per acre.
2. Uniformity in tree size and growth rate, to facilitate mechanical harvesting.
3. Relative uniformity of fiber length within and between trees of the same species.
4. Relative uniformity of spring-wood/summer-wood ratio within and between trees of the same species.

Although the newer pulping processes are adaptable to many species, a variety of species in the area is necessary to supplying the diverse product demands. It is essential, therefore, for the economics of the industry that a large renewable supply of a number of improved species be available.

Pulpwood and Tree Improvement

The possibilities for meeting the increasing demands for pulpwood through tree improvement concomitant with other intensive management

practices are good. Industry has amply demonstrated its abililty to adequately utilize the fibrous material available when this material is in adequate supply and in the right place. Factors of quality such as color, fiber length, and objectionable tars and resin have been dealt with largely through technical innovation in processing. The utilization of an ever increasing variety of species, sawtimber by-products such as chips, and substitute plants such as kenaf all illustrate the versatility of the pulp and paper industry and the rapidity with which technical processes can be evolved and adapted.

The adequacy of the supply of fiber, its relative uniformity within the species, and species suitabililty for sites close to mills are problems to which tree-improvement programs can well be directed.

Plywood and Veneer

The per capita use of plywood and veneer has risen steadily and National demands are expected to continue to rise. The *Timber Trends* report (USDA Forest Service 1965a) predicted that by the year 2000, demand for plywood and veneer would rise to 270 percent of the 1962 consumption. The projection indicated that softwood plywood would account for most of the increase.

Domestic logs are the raw material for practically all of the softwood plywood and veneer consumed in the United States. Douglas-fir, the major species used in the manufacture of plywood, accounted for 88 percent of the total softwood veneer logs used in 1962. An increasing number of other softwood species is being utilized, including western hemlock, western pines, larch, true firs, redwood, cedar, and southern pines.

Tree improvement, as well as other silvicultural research, is very active in the South and West. The intensification of forest management that is expected to follow will assure that the projected demand for softwood plywood in the United States will continue to be supplied from these areas, although changes in plywood tariffs could affect the outlook (USDA Forest Service 1965a).

In the North-Central Region at the present time there are no reported softwood veneer plants operating. There is, however, a large hardwood veneer industry. Seventy-nine veneer mills were operating during 1966 in the Region. Thirty-five were container veneer mills and the others manufactured face, core, crossband, or specialty veneers.

In the Lake States yellow birch, hard maple, and red oak veneers were manufactured in that order of volume. Nearly 28 percent of the birch was imported from Canada whereas virtually all of the maple and red oak veneer logs were produced in the Lake States. The demand for birch is increasing while the local supply is decreasing. There are strong indications that imports of birch from Canada will have to increase to meet the demands (Knutson 1967, Blyth 1968b).

In the Central States in 1966, 24 mills produced commercial and face veneers and 12 container plywood. More black walnut was cut for veneer than any other species: nearly 15 million board feet. Cottonwood logging accounted for another 6.2 million board feet, the second highest species volume cut. Minor amounts of other species were used

Anticipated Production Trends in the Region's Hardwood Veneer and Plywood Industry

National continued rapid growth in per capita consumption of hardwood plywood is anticipated.[1] Consumption of hardwood-based panels could increase by 300 to 400 percent over the next 30 years but imports and synthetics will control large shares of the market. However, the Region is one of the largest suppliers of quality native hardwoods. Although regional trends indicate that the supply of hardwood veneer logs could possibly meet the demands for domestic hardwoods through the year 2000, the quality is declining and some species would have to be substituted for others. Much of the existing timber inventory consists of small trees of low-value species. In the years after 2000 hardwood veneer logs of even mediocre quality would be in short supply under our present intensity of management.

The Black Walnut Situation

The future supply and projected demands of black walnut have been considered intensively in recent years because of its past and present extremely high market value. Future demand for black walnut timber will depend largely on per capita income and consumer preference changes. Demand will probably continue to be strong but it will be increasingly difficult to obtain the quality of wood desired.

A comparison of current growth and cut using medium growth estimates and the latest timber cut estimates converted to standard units shows that the current annual cut of all grades of walnut timber is slightly less than the growth occurring annually on commercial forest land.

However, when quality is considered, the picture is different. The annual cut of high quality materials exceeds the annual increase in equal quality material. Supplies of quality logs are dwindling (Quigley and Lindmark 1966).

The outlook for high-quality walnut timber of sufficient quantity to supply current and increasing demand is not good. Both growth and cut will probably decrease in future years (Fig. 2). Intensive management of our present resource and the establishment and management of walnut plantations of superior stock are the only sure ways to provide increasing quantities of high-quality walnut timber.

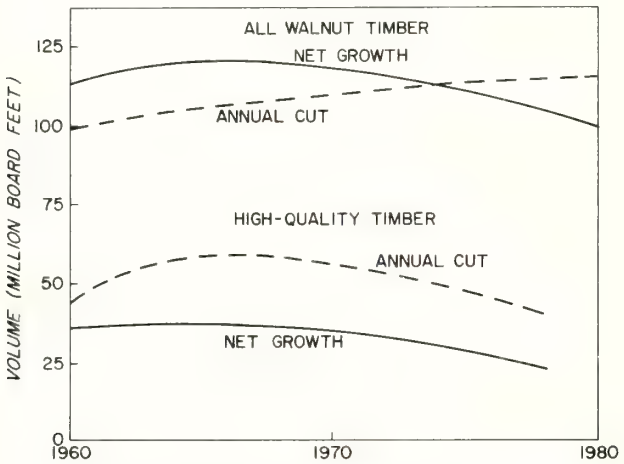

Figure 2.—Probable growth-cut relationship for walnut timber. (Source: Quigley 1966)

Hardwood Plywood and Veneer and Tree Improvement

Because the climate of the Region is uniquely favorable to growing high-quality hardwoods, attention could logically be given to improving the quality and quantity of these species and thus develop the full potential of the Region's forests. Tree improvement programs can contribute to both of these objectives.

Opportunity also exists for increasing yield and quality by means of timber stand improvement.

Tree improvement to increase the veneer quality of hardwoods will likely have little impact upon market situation before the year 2000 and for several decades thereafter.

Lumber

Projections of lumber consumption in the year 2000 vary greatly. The *Timber Trends* report predicted National demands for lumber would rise 43 percent over the 1962 level while Hilliker[1] projected demands in 2000 to be about equal to the demands of 1962.

Currently 88 percent of the Nation's lumber production is concentrated in the West and South. Hilliker[1] estimated that slight intensification of forest management practices in these areas will probably meet the projected demand.

In general, the relative importance of the Region as a lumber producer has diminished greatly since the start of this century. The present industry and the outlook for lumber production varies from State to State. Wisconsin's share of total domestic production, for example, has declined from a high of about 10 percent in 1900 to about 1 percent in 1954. On the other hand, in Illinois, although the number of mills decreased drastically after World War II, the production of lumber increased 38 percent. But the quality of saw logs as well as veneer logs is generally decreasing. Much timber stand improvement will be necessary to maintain the present industries (Essex and Gansner 1965).

Annual lumber-log production in Missouri is expected to reach 500 million board feet by 1989, a level attained only at the turn of the century and during World War II. Logs will decrease in quality and softwoods will represent an increasing percentage of the total volume (Gansner 1965).

The precise place of the North-Central Region as a supplier of lumber in the future is difficult to define. The supply of lumber beyond the year 2000 will be to some extent determined by the cuts of timber for veneer and pulpwood, both products which apparently will be in greater demand.

It would appear that with good management the demand for quality hardwood veneer could take most of the maple, yellow birch, and oak. An expanding Lake States pulp and paper industry will probably utilize the aspen and low grade hardwoods, plus the smaller pine and spruce.

The Area and Condition of the Commercial Forest Land Within the Region

In the Central States (Indiana, Illinois, Iowa, and Missouri) the economy is largely agricultural and industrial, yet 1 out of 5 acres is still forested. This 25-million-acre area of commercial forest land is 98 percent hardwood, mostly in the oak-hickory and bottomland hardwood type. In these States, 90 percent of the forested land is privately owned (USDA Forest Service 1958; Dickerman 1954). The forested region of the Lake States contains 51 million acres of commercial forest land, 70 percent of which is in hardwood types. Private ownership amounts to 60 percent (table 3 in Appendix).

Although it appears certain that changes in land use will continue, it is difficult to estimate their extent. Competition among farm, urban, and forest use for rural land probably will continue for the next several decades. Urban use will replace agricultural or forest use most noticeably in the southern part of the Region (Quinney and Schallau 1963).

Of greater concern to the wood producer is the inevitable shift from commercial to noncommercial uses of forest land. The multiple-use concept allows for recreation in forest management; recreational use of forest land is increasing at a greater rate than are other uses, however. Indeed, visits to National Forests are expected to increase 8-fold by the year 2000 (USDA Forest Service 1961). Today about 50 million people live within 500 miles of the center of the forests of the Lake States, a figure projected to rise to 90 million by the year 2000 (U. S. Department of Agriculture 1963). Timber growing and harvesting will have to be modified in order to satisfy the recreational needs of the future.

Tree Improvement Possibilities Within the Region's Forests

The science of genetics can be applied to forestry to increase the per-acre yield and quality of forest products but only when the improved species are planted or seeded. It becomes pertinent, therefore, to evaluate the commercial forest land in an attempt to analyze:

1. What areas will be available for improved trees to be planted when they become available.
2. In order to meet national demands, in what timber types will the planting of genetically improved trees to be the best alternative for increasing the productivity of the Region's forests.

Since the 1930's much planting has been done throughout the Region, mostly on open land, burned and clearcut areas, and abandoned farmland. Today good, open, tree planting sites are becoming scarce, and when genetically improved seedlings start coming from the Regional nurseries in quantity, high-quality open sites will be virtually nonexistent. Hence, the forest planner must look to other means of increasing productivity of his forest.

Conversion to other species that can better occupy the site, or have been developed and bred specifically for use on these sites, is a realistic alternative to continuing management of the same species (fig. 3). In other cases, conversion may be removal of an existing stand and replacing it with a stand of an improved strain of the same species, especially on good sites. Both possibilities exist in the forests of the Region.

In one recent study, Stevens and Wertz[4] were able to project a 60 percent increase in productivity just on the basis of matching species to site. The National Forests of the Region plan type conversion on over 200,000 acres of poorly stocked land in the next 10 years. Conversion is thus not only desirable, but is being actively practiced within the Region.

Much commercial forest land in the Region is relatively unproductive at the present time. Of its 76 million acres, over 45 million acres — nearly 61 percent, are classed as "poor" or "medium" sites on the basis of existing forest cover. Included are about 18 million acres in the oak-hickory type; about 7 million acres in the aspen-birch type; about 6 million acres in the maple-beech-birch type; and about 5 million acres in the elm-ash-cottonwood type (Table 4, Appendix). This vast acreage scattered throughout the Region offers a challenge to the forester and to the practice of tree improvement.

The approximate condition of the Region's forests and possibilities of stand conversion are *generally* portrayed in Figure 3. In practice, each

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[4] *Stevens, Mervin, and Wertz, William. Soil-timber species mix, a study. (In preparation for publication, USDA Forest Serv., Eastern Reg.)*

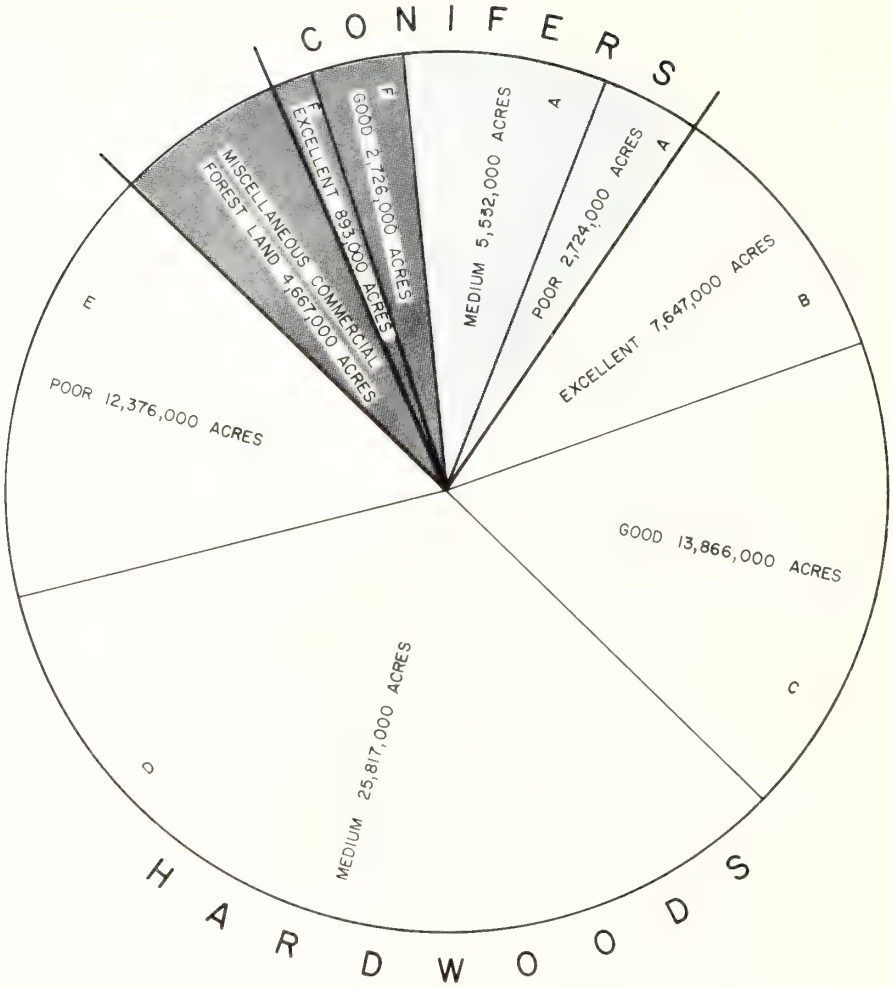

Figure 3.—Acreages of commercial forest land by site classes showing tree improvement possibilities.

A – Convert to species better adapted to site.
B – If improved stock is available, plant to convert to better hardwoods.
C – Plant to improved hardwoods or change species composition by timber management.
D – Consider conversion of some acres to softwoods or other hardwoods.
E – Consider conversion to conifers.
F – Reserve for highly improved stock.

stand needs to be thoroughly appraised before accurate judgments and recommendations can be made.

No attempt should be made to improve trees for poor sites *for that species*. The genetic potential of a species can best be realized when grown under optimum site conditions. It probably will be, particularly in the case of high-value hardwoods, the best practice to plant the improved trees on the best hardwood sites. However, utilizing the less demanding species on the poorer sites is an accepted forestry practice. There are fewer alternatives to increasing yields or the quality of product from a poor site. Timber stand improvement practices such as thinning, pruning, etc., cannot offer much hope of economically increasing the value of the timber on these sites.

All forest stands with a low site index are not reasonable candidates for conversion to other species, or improved strains of the same species, because other species may not produce well on the particular site either.

In the Lake States emphasis should be put on tree- improvement programs to develop species lines that can be used to convert poor-site aspen-birch, maple-beech-birch, and spruce-fir types. Selection and development should be concentrated on species that will likely be in demand and are able to use these sites most efficiently.

In the conifer types the need for conversion to other species is not so well defined. White cedar, tamarack, and black spruce types occupy a high percentage of medium and poor sites, yet the opportunities for substituting species on these sites appear limited.

Perhaps the best opportunity for improving the production on the upland conifer areas by means of tree improvement is by replanting stands as they are harvested to improved types of the same species. There is need for more species alternatives from which to choose for these locations.

In the Central States the biggest problem is the poor oak-hickory sites, if we are to consider them a part of the commercial forest acreage. At present, it is not economical to manage oak-hickory stands on the poorer sites. As the demand for forest products increases, the pressures on the land for all uses intensifies, and as property taxes rise, conversion of these stands to species that can better utilize the site may become more practical.

The better sites of both the elm-ash-cottonwood and the oak-hickory may well be managed to produce the species that are there now – or they may be replanted with improved types of the same species as they become available. Some stands in these types, however, could also be modified to include high-value hardwoods such as black walnut.

Alternatives to Meet Projected Demands

The Nation's commercial forest land is capable of producing much more than the growth projected on the basis of current forest management (USDA Forest Service 1965a). A number of technical forestry measures could be strengthened to bring future supplies of timber in line with projected demands.

1. Timber stand improvement holds the most promise for increasing the timber supply over the next few decades. In many areas, timber stands of desirable trees could be developed by thinning, removing cull trees, or other cultural work.

2. *Planting or seeding productive sites, particularly to genetically improved trees, also offers opportunities for increasing future yields of timber, particularly after the year 2000. Although nationally tree planting has covered about 1.3 million acres annually in recent years, more than 100 million acres of commercial forest land are at present either "nonstocked" or "poorly stocked" with trees of acceptable quality or species.*

3. Increased protection from fire, insects, disease, and other destructive agents offers additional possibilities for expanding wood supplies. Losses have been greatly reduced in recent decades, but mortality in 1962 still totaled 20 billion board feet or 35 percent of the net annual growth of timber.

4. Closer utilization of timber in the woods and in manufacturing plants also would stretch the available timber supplies. Salvage of dead timber and greater use of logging and other manufacturing residues could augment supplies of round timber.

5. Continuing increases in efficiency in forest industries would permit a larger output of products from a given supply of raw material.

Although tree improvement programs and practices can, in some cases, help meet the increasing demands for forest products in the Region, they are not the *only* means to economically increase the supply or improve the quality of our wood products. Alternatives for reaching the desired objectives are available and should be recognized in setting program priorities.

Reasonable forestry alternatives for meeting demands diminish as the quantity of material required increases simply because there is so much more acreage and so many more individual trees involved. For example, it may be possible to apply intensive timber-stand improvement practices on a few thousand acres each year; it is out of the question on millions of acres. There is a practical limit to the area that can be effectively treated in this manner. Similarly, the cost of insect and disease control may become prohibitive as the acreage of affected stands increases.

The rotation ages of the various species also influence the choice of forest practice to increase yield or quality. The cost of any one timber stand improvement operation must be prorated over the length of the rotation when considering returns on investments. Hence, tree improvement may offer an attractive alternative for short

rotations when the annual prorated cost of other practices would be too high.

Another factor to consider is the relative unit cost of the wood produced. Although the future relative cost of any species is difficult, if not impossible, to determine, the general laws of supply and demand can be applied to make some rational judgments. If the unit value of wood is high and remains high at the time of harvest, there can be a greater investment in timber-stand improvement. As the unit value increases, alternatives for yield or quality improvement increase.

These general concepts point out that in the North-Central Region, tree-improvement programs can be used to best advantage in increasing the supply of pulpwood, with lesser advantage when applied to species intended for other purposes. The projected demand for pulpwood in the Region is much greater than the projected total demand for hardwood veneer and plywood or lumber. Similarly, the unit value for pulpwood is much lower than for the other products. Hence, tree improvement programs along with intensive culture and total tree utilization appear to offer the best alternatives for increasing the supply.

Also, there is sufficient commercial forest land in the Region in good and excellent site classes to meet the demand for many species utilized mainly for veneer or lumber with intensified timber-stand-improvement practices. There are, for example, over 5 million acres of excellent to good oak-hickory sites capable of producing high yields of those species without the use of genetically improved species. There are over 3 million acres of the maple-beech-birch type (largely sugar maple) in excellent or good site classes which, with intensified management, could greatly increase the production of sugar maple.

Considering that to meet the National demand for all hardwood products (veneer and lumber), only 0.6 billion cubic feet needs to be added to the projected cut, quantity demand for these products could generally be met by practices other than tree improvement.

Tree Improvement as an Investment

Cost-benefit analysis is desirable when evaluating management alternatives for individual species or stands. At present published data are insufficient for precise evaluations of this nature (Namkoong, Barefoot, and Hitchings 1967). However, it is possible to predict in general terms the investment returns on tree improvement programs.

The analysis of red and jack pine improvement program models given by Lundgren and King (1966) presents long- and short-term alternatives. The short-term program bases the selection of clones for seed orchards on 5-year progeny tests. For both species the highest return on invested capital under most conditions favored the short-term programs. A slightly higher increase in site index would be necessary with jack pine than with red pine to yield comparable rates of return. Increasing the site index of class 55 land by only 2 units resulted in a calculated investment return of 7.5 percent for red pine and 6 percent for jack pine. Thus only a slight gain in site index would be necessary to justify any of the suggested programs. Lundgren and King stressed the fact that the best rates of return could be attained on the best sites for the species.

Pitcher (1966) discussed the cost of white spruce seed obtained from established seed-production areas. He calculated that an increase in rotation volume yield of as little as 0.25 percent would offset all the costs of development.

Similarly, Lester (1969) discussed genetic improvement of white spruce as an investment alternative. Assuming a compound interest rate of 4 percent, he calculated the cost of improved seed to be $10.35 per acre. Considering a 45-year "breeding period" and a 75-year rotation, a 9.2 percent increase in yield would be necessary to justify this cost. Current genetics research indicates increases in white spruce yields of about 25 percent. This would mean a per acre profit of $17.81 over costs or $1,252,300 for the 70,000 acres that were assumed to have been planted.

Swofford[5] determined the internal rates of return based on expected gains resulting exclusively from genetic improvement of nursery stock. Costs included tree selection, orchard establishment, and progeny testing. Expected benefits were estimated for (1) rotation age reduction, (2) quality gain, and (3) volume gain. Calculated internal rates of return were:

Longleaf pine	14 percent
Loblolly pine	18 percent
Slash pine	19 percent
All species	15.5 percent

Clearly, tree-improvement programs can be sound investments that yield respectable rates of return.

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[5] *Swofford, Thomas F. An economic evaluation of tree improvement on the Alabama National Forests. USDA Forest Serv., Southern Reg. 1968.*

Status of Genetics Knowledge

Applied tree-improvement projects must be founded on genetic principles. Information derived from basic genetics research, therefore, becomes extremely relevant. The tree breeder must have some genetic guidelines to start with, or he will find the work diverted to studies set up to determine *how* to accomplish the desired gains rather than projects basically designed to produce improved trees. It is extremely important to recognize that there must be close coordination between action or developmental programs and research. There must be a continuous flow of information from genetics research to tree-improvement projects and a feedback of information from these applied programs to research. Management and research must be closely linked.

An extensive review of all forest tree genetics research relating to potential tree-improvement programs in the North-Central Region would be too voluminous to consider as part of this analysis. The work is well documented, however, in several bibliographical publications (Wright 1955; Libbey *et al.* 1956; Wright and Finn 1960; Wright and Rudolf 1962).

Genetics Research Programs in the Region

The earliest forest tree improvement in the area began before 1900 when tests of the adaptability of several exotic tree species were included in some of the early forest planting. However, planned experiments to determine variation within a forest tree species did not begin until 1928, when Carlos Bates of the Lake States Forest Experiment Station began a study of red pine seed sources. This has been followed by other genetic and forest tree improvement research at the North Central Forest Experiment Station, the State universities and colleges, and forest industries (Rudolph 1956).

Limstrom (1965) reported the latest research findings and considered judgment of foresters experienced in tree improvement for species used in planting programs in the Central States.

Rudolph (1966b) reported on genetics and related research at the Lake States Forest Experiment Station during the period 1924-1965. This report listed 172 papers published by staff members of the Station with indexes by subject matter and species names.

More recently, Jeffers[6] summarized 10 years of research at the North Central Station's Institute of Forest Genetics. Work at the Institute has concentrated on *Picea* spp., *Betula* spp., *Pinus banksiana*, *Larix laricina*, *Abies balsamea*, *Thuja occidentalis*, and *Pinus strobus*.

Some genetic research has also been published through the auspices of several regional forest tree improvement committees:

1. The Lake States Forest Tree Improvement Committee
2. The Northeastern Forest Tree Improvement Committee
3. The Central States Forest Tree Improvement Committee
4. The Committee on Forest Tree Breeding in Canada.

The committees have sponsored conferences annually or biennially, the published proceedings of which report on a broad variety of genetic research studies.

Provenance—or seed-source—testing has been conducted as a cooperative project with the "NC-51 Committee." The Committee is composed of one forest research scientist from each of 10 State Agricultural Experiment Stations in the North Central Region, a representative of the USDA Forest Service, and a representative from the U.S. Cooperative State Research Science as organized in 1960 under provision of the Hatch Act. The purpose of the project is to conduct a cooperative research program in forest tree improvement through selection and breeding. Range-wide provenance tests have been started with 12 species. Results of work of the NC-51 project are rather limited due to the short time the studies have been in progress.

Rudolph (1966a) summarized basic and applied genetics research by species, agencies involved, and subject matter. In 1965 there were 133 research projects conducted by 12 agencies in Wisconsin, Michigan, Minnesota, and North Dakota.

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6 *Jeffers, Richard M. Ten years research at the Institute of Forest Genetics, Rhinelander, Wisconsin. (In preparation for publication, N. Cent. Forest Exp. Sta., USDA Forest Serv., St. Paul, Minn.)*

The following agencies in the Region were reported to have forest genetics research in progress: North Central Forest Experiment Station, University of Minnesota, University of Wisconsin, Michigan State University, University of Michigan, University of Illinois, Iowa State University, Purdue University, University of Missouri, Michigan Technological University, U.S. Forest Products Laboratory, and the Institute of Paper Chemistry. Several other organizations and agencies are involved in applied breeding and developmental work (Rudolf, 1966a).

Significantly, of all the research projects in the Lake States, 73 percent are concerned with three genera: *Pinus*, *Picea*, and *Populus*.

Work in progress on the genus *Pinus* includes 52 studies involving *Pinus resinosa*, 47 studies relating to *Pinus banksiana*, and 35 studies concerning *Pinus strobus*. *Pinus sylvestris* is the only exotic pine that has been the subject of any significant studies in the Lake States (22 studies).

Picea glauca was the subject of 52 (or 46 percent) and *Picea mariana* of 22 (or 20 percent) of the spruce studies (Rudolf, 1966a) (fig. 4).

Among the hardwoods, the genus *Populus* has received most research attention (fig. 5). In the Lake States, 92 of the 142 studies dealing in the genetics of hardwoods involved the genus *Populus*. Although most of the studies in the Lake States involve *P. grandidentata* or *P. tremuloides*, internationally there has been much research on the genetics and breeding of the *Aigieros* poplars. The genera *Betula* and *Juglans* are the subject of more recent studies in the Region.

Shortleaf pine *(Pinus echinata)* is currently receiving attention in tree-improvement programs in Missouri. Dorman (1962) reviewed the literature on the species and outlined a proposed breeding program.

Vegetative propagation techniques for the species of interest in the Region are well established by a number of authors. Although more knowledge regarding air layering, rooting of fascicles, and more basic knowledge of the physiological processes involved is needed, it is possible to start improvement programs with the knowledge

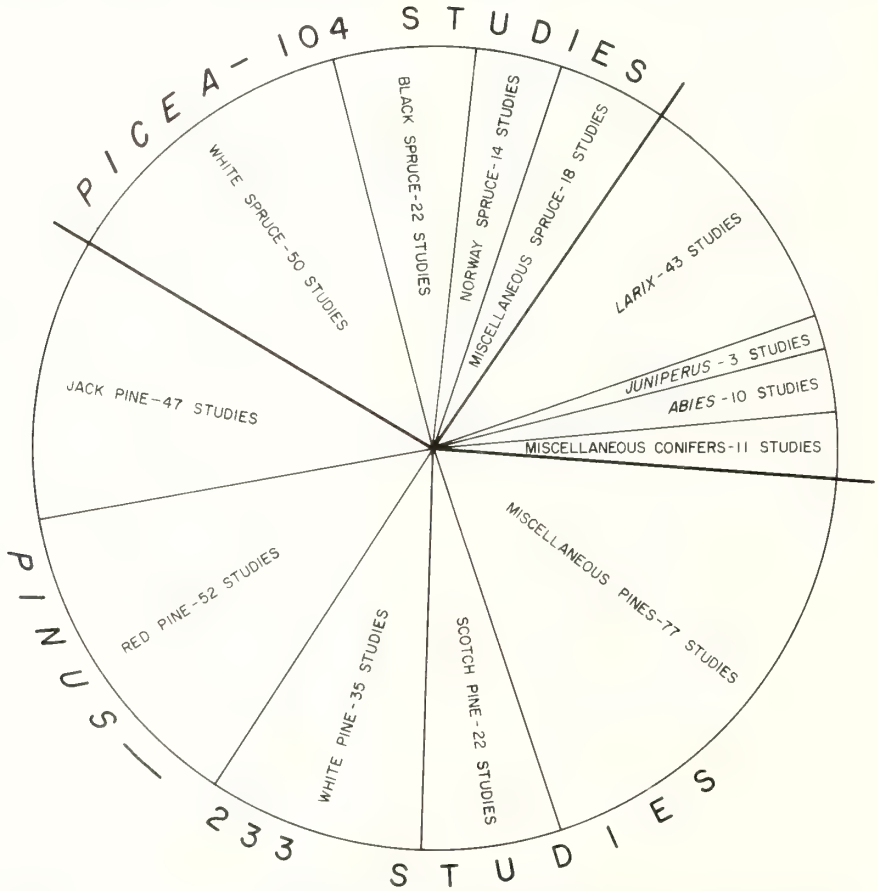
PICEA - 104 STUDIES
WHITE SPRUCE - 50 STUDIES
BLACK SPRUCE - 22 STUDIES
NORWAY SPRUCE - 14 STUDIES
MISCELLANEOUS SPRUCE - 18 STUDIES
LARIX - 43 STUDIES
JUNIPERUS - 3 STUDIES
ABIES - 10 STUDIES
MISCELLANEOUS CONIFERS - 11 STUDIES
JACK PINE - 47 STUDIES
RED PINE - 52 STUDIES
WHITE PINE - 35 STUDIES
SCOTCH PINE - 22 STUDIES
MISCELLANEOUS PINES - 77 STUDIES
PINUS - 233 STUDIES

Figure 4.—Species or genus of 404 genetics research studies of conifers in the North Central Region in 1965.

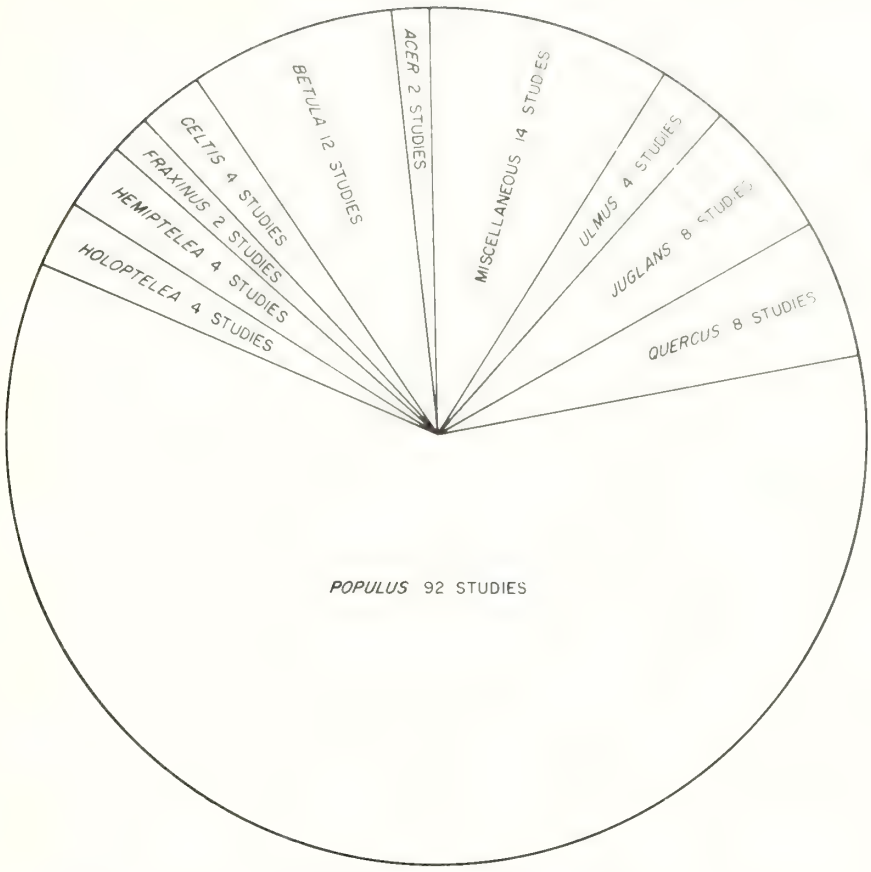

Figure 5.—Species or genus of 154 genetics research studies of hardwoods in the North Central Region in 1967.

available. These techniques as they apply to the Region is probably best summarized by Nienstaedt (1959) and Nienstaedt *et al.* (1958).

It is evident from the literature that the most genetics research has been done on the following 11 species currently of economic importance in the North Central Region:

Pinus resinosa
Pinus banksiana
Pinus strobus
Picea glauca
Picea mariana
Pinus sylvestris
Pinus echinata
Betula spp.
Juglans nigra
Larix spp.
Populus spp.

Although much additional research is needed, sufficient genetic knowledge has accumulated on these species to provide agencies contemplating tree-improvement programs with enough information to begin.

Developmental Programs in the Region

There are a number of developmental programs underway within the North Central Region. These programs differ in intensity but they do indicate the extent of the interest in developmental work. A brief summary of these programs will illustrate the point.

Industry

Forest-tree-improvement research in the Lake States so far has concentrated on basic or quasi-basic problems in an effort to accumulate a store of knowledge that may eventually be adapted to practical forest management. Because of the nature of the general program, the momentum of this work has been set by public and educational research organizations. But many of the projects

could not have come so far without the cooperation of the Lake States forest industries.

Cooperation by industry in tree-improvement research work has been in three general categories:

1. Grants of money to support research. (The Institute of Paper Chemistry's genetics program, which is supported by paper companies, is an example of this type of cooperation.)
2. Release of land or other facilities for use by the research institution.
3. Actually sharing the work. (Some of the North Central Forest Experiment Station's seed source studies are this kind of cooperation.)

In addition to cooperative research studies with public agencies, several companies have developed, or plan to develop, seed orchards of *Abies balsamea*, *Picea glauca*, *Picea mariana*, *Pinus banksiana*, *Pinus resinosa*, and *Pinus strobus*. Others have reported the establishment of red pine seed-production areas.

In application of tree-improvement knowledge, industry has taken the lead in one field — the growing of forest planting stock from seed of presumably better-than-average genetic quality. The seven industrial forest nurseries in the Lake States produce about 7 million trees annually. All of these nurseries have a seed-quality program wherein at least part of the seed they require is collected under direct company supervision from selected trees and stands (Macon 1960).

The Institute of Paper Chemistry at Appleton, Wisconsin, has had an industry-supported program in "Aspen Genetics and Tree Improvement" since 1954. Aimed primarily at improving growth rate, form, and wood quality, an action program was begun in 1968 by the Institute of Paper Chemistry to demonstrate the biological potential of natural and improved aspen.

The American Walnut Manufacturer's Association supports research and development programs in black walnut, particularly through the Black Walnut Breeding Project at Carbondale, Illinois. Its members contribute plant materials for further trial and evaluation.

States and other Public Land-Managing Agencies

Each of the States in the North-Central Region is involved in developmental programs at one level or another. The State of Illinois, through the University of Illinois at Urbana, is supporting developmental breeding work with cottonwood. The State of Indiana is developing a black walnut seed orchard near Mitchell. Combined research and development programs for improved strains of red and jack pine are conducted by the Michigan Department of Natural Resources through the State universities. The Minnesota Conservation Department has participated in the outplanting of a black walnut seed source study and the establishment of red pine production areas. The Department of Natural Resources in Wisconsin is supporting research and development programs in red pine and balsam fir in cooperation with the University of Wisconsin. All three Lake States are cooperating in a joint effort with the USDA Forest Service to produce strains of white pine resistant to blister rust. The State of Missouri has a full time tree-improvement specialist assigned to developmental work in that State An active selection program is underway there in black walnut, red-cedar, and cottonwood.

National Forest-Tree-Improvement Programs

Forest Service programs active in the North Central Region involve mainly white and black spruces; red, jack, and white pines; and yellow birch in the Lake States. In the Central States programs are underway with shortleaf, loblolly, and white pine; black walnut; and yellow-poplar. Some work is also in progress with red oak, basswood, and black cherry. Major emphasis has been on volume yield in all species with consideration given to the comparative quality characteristics.

Three 50-clone seed orchards of white spruce serving separate geographic areas within the Lake States are partially established in the large 550-acre seed orchard on the Nicolet National Forest in Wisconsin. Similar orchards are planned for black spruce. A clonal breed arboretum containing over 700 rust-free selections of white pine is also planned and partially completed within this orchard complex. Selections of white pine resistant to the weevil (*Pissodes strobi*) are being cloned for later outplanting in the orchards.

A 15-acre, half-sib seedling progeny test and seed orchard was established in 1964 on the Huron-Manistee National Forest in cooperation with Michigan State University. It contains 290 individual tree collections of red pine from the Lake States area.

In the Central States, a 50-clone orchard of shortleaf pine is being developed in connection with the tree-improvement program of the National Forests in the Southern Region. Estab-

lished in Arkansas, this 85-acre orchard will eventually supply up to 2,000 pounds of seeds annually for reforestation of the Clark and Mark Twain National Forests.

In the North Central Region, 33 seed-production areas were established with 6 species from 1960 to 1966. Cones have been harvested from some of these areas and seedlings outplanted on reforestation projects on the National Forests.

Additional programs are under development with these and other species in the eastern part of the Eastern National Forest Region.

Situation Summary

The National need for wood products is projected to increase 80 percent by the year 2000 and there is an estimated continued growth in demand at an unknown rate after 2000. The projected cut is short of the projected consumption by different amounts depending on the product.

According to the *Timber Trends* report and Hair (1967) the National production of roundwood for major timber products must increase by the following amounts if they are to meet the demands of 2000:

	Billion cubic feet	*Percent consumption increase*
Pulpwood	5.8	400
Softwood lumber	1.1	140
Softwood plywood and veneer	.4	242
Hardwood lumber	.4	150
Hardwood veneer	.2	250

The supply of these products must be produced on a constantly diminishing area due to uses of the land for other than timber production.

Emphasis on increasing the quantity and quality of raw material from the Region's forests should be first on pulpwood, both hardwood and softwood, and second on hardwood veneer. There is little evidence that a significant increase in the lumber industry will develop in the Region as most of the demands for lumber will continue to be met by the West and South. Generally, the first concern for tree improvers should be, therefore, increased fiber yield per acre.

It is essential to consider *all* the possibilities of improving the quantity and quality of our forest products. Timber-stand-improvement, including pruning, thinning, disease and insect control, and controlling stocking are all measures that need to be considered as alternatives to and along with tree-improvement practices.

Of the 76 million forested acres in the Region, 46 million acres (or 61 percent) are "medium" or "poor" sites. To meet the demands on the forests for wood products it seems inevitable that forest managers will sooner or later have to consider converting to other species that can utilize these sites more efficiently.

In the Lake States first priority is to develop improved species so the portion of the 13 million acres of aspen-birch types on "medium" and "poor" sites, that appears to be excellent site for other species, can be converted. Second, attention should be given to improving the species now existing in quantity on the better sites and to replace the trees there with improved strains of the same species. This is particularly relevant for the 7 million acres of "good" aspen-birch stands and the 3 million acres of maple-beech-birch stands on high-quality sites.

In the Central States tree improvement should be aligned to (1) provide improved alternate species for converting at least part of the 18 million acres of medium and poor oak-hickory sites that appear to be excellent or good sites for the alternate species; (2) improve the several native high quality hardwoods in answer to the demand for the growing veneer and furniture markets; and (3) consider the improvement of cottonwood, elm, and ash so as to better utilize the areas now occupied by these species.

Program Plans

In this analysis four factors for determining general species, priorities for the improvement programs have been explored:

1. The National demand for forest products.
2. The area and condition of the Region's commercial forest land.
3. Alternative means of meeting demands.
4. The amount of basic genetics knowledge available for various species.

Because of the status of basic genetics knowledge available, tree-improvement programs in the Region are currently best confined to the

genera and species for which there are adequate genetic guidelines. The tree improver cannot effectively and efficiently breed trees without some knowledge of variability within the species and the heritability of the species traits he wishes to improve.

For the North Central Region, it has been pointed out that so far most relevant genetics background information has been accumulated on 11 genera and species, listed alphabetically:

1. *Betula alleghaniensis*, yellow birch
2. *Juglans nigra*, black walnut
3. *Larix*, spp., larches
4. *Picea glauca*, white spruce
5. *Picea mariana*, black spruce
6. *Pinus banksiana*, jack pine
7. *Pinus echinata*, shortleaf pine
8. *Pinus strobus*, white pine
9. *Pinus sylvestris*, Scotch pine
10. *Pinus resinosa*, red pine
11. *Populus*, spp., aspen, cottonwood and poplar

Some of the species in this list have much greater potential than others for increasing the quality and quantity of Regional forest products through tree improvement.

The analysis of projected demands for forest products, the availability of optimum planting sites in the future, and alternatives for meeting the demands make it possible to at least generally evaluate the probable contribution each of the 11 species, if genetically improved, might make.

Specific priorities, within the list of 11 species can best be determined by the agency or organization concerned after considering all four factors in light of its own management objectives.

The following "Species Summary" discusses the potential of each species in detail, prescribes specific developmental tree-improvement programs, and suggests applied research needed to implement the use of the improved trees.

No projection involving the demand for forest products for the year 2000 or beyond can be completely accurate. Therefore, programs following the recommendations presented here may not precisely meet the needs of the future. Because of the years involved, the danger of breeding obsolescence into our forestry programs is a very real one. Consequently, other factors being equal, those species well adapted for *several* uses are judged to be better candidates for tree-improvement programs than are "single-purpose" species.

Wright (1962) discussed the various methods available to the tree breeder and the genetic gains to be realized from each of the techniques. Where heritability for a specific trait is high, mass selection methods are effective and economical. When heritabilities are low or suspected to be low, then family selection methods can produce more genetic gain per unit cost. These concepts are considered in the recommendations presented for improvement projects.

Species Summary

Yellow Birch *(Betula alleghaniensis)*

One of the more versatile hardwoods for veneer, lumber, furniture, cabinets, and flooring, it is a decreasing component of the maple-beech-birch timber type of the Lake States. There appears to be no effective way of increasing the amount of yellow birch in the stands other than by planting. Because of the large acreages of this timber type, genetics and silvicultural work should be accelerated in this species.

Yellow birch tree-improvement programs should begin with phenotypic selection using the guides developed by Clausen and Godman (1967). Since the species flowers early and abundantly, collection of open-pollinated seed from the best phenotypes and the establishment of seedling seed orchards would seem to be the most efficient approach. Little advantage is to be gained by grafting. Heritability estimates for the important economic traits are not available. Recurrent selection within the F_1 breeding population may prove productive.

Black Walnut *(Juglans nigra)*

Although the current demand for black walnut is high, the variety of end products is somewhat restricted because of the high price. However, black walnut wood has commanded a premium price for more than 300 years and the future demand will probably continue to be high.

Black walnut fits nicely into specific ecological niches in the southern part of the Region. Some of the problems of quality – i.e., color and grain – cannot be controlled by forestry practices. As with all nut species, intensive breeding programs are expensive. Black walnut programs should probably include only the suggested steps listed below. These programs plus increasing the planted acreages and intensive silviculture should meet the demand considering the relatively moderate increase necessary.

Black walnut tree-improvement programs

should start with phenotypic selection of outstanding individuals, concentrating the selections within the optimum development range but including specimens from a north-south and east-west transect. A half-sib seedling seed orchard should be established on a good site with concurrent half-sib progeny tests at several locations. The seed orchard should be rogued of poor families at about 20 years based on mean family performance in all the progeny tests. Clonal orchards and controlled pollination seem impractical at this time, pending further heritability data. Cultural methods of weed control, fertilization, irrigation, and first-log pruning should be practiced in the progeny test only if they can be expected to be standard practices in black walnut management. Progeny tests should sample the oak-hickory types as well as the deep cove types.

Larches *(Larix)*

There is much interest in the larches because of their juvenile growth rate, their adaptation to various sites, and their excellent pulping and construction lumber qualities. Genetically, heterosis (hybrid vigor) is manifested between many crosses within the genus. The potential of the genus in the Region appears to be high. Additional basic genetics research is desirable before intensive tree-improvement programs can be started.

Tamarack selections of superior phenotypes should concentrate first on volume yield. A second selection program should aim at sawfly resistance. Separate clonal seed orchards should be established followed by progeny tests to evaluate combining abilities both within and between orchards.

White Spruce *(Picea glauca)*

White spruce is biologically a productive species. When grown on high-quality sites in southeastern Ontario, it produced 5,705 cubic feet per acre in total wood at the end of 40 years (Stiell and Berry 1967). By comparison, red pine on an excellent site in Minnesota produced 4,490 cubic feet at the end of 40 years (Buckman 1962).

Although the consumption of spruce in the pulp industry has been declining, the reason for the decline is not related to the quality of wood as a pulp species. On the contrary, its relatively long fiber length, lack of objectionable resins, and color of pulp produced make it a preferred species. Although the newer pulp-making processes are not limited to spruce and a few other species, as is the sulfite process, spruce can be utilized effectively by them. Should changes in economics of technology cause the demand for spruce pulpwood to decline in spite of its availability, the potential of white spruce as a plywood species is good (Shottafer, 1968). Because of these factors and the large acreage of commercial forest land in the Lake States which from an ecological point of view needs conversion to white spruce to markedly increase its productivity, intensive developmental programs are well justified.

Programs now underway in the Lake States are based on phenotypic selection in wild stands. Greatest weight should be given to volume yield and growth rate. Clonal seed orchards should be established and progeny tests set out to estimate combining abilities. Recurrent selection within the progeny tests should be productive.

On a mass selection basis, selection of superseedlings in nursery beds may be a relatively inexpensive way to obtain significant growth increases. Superseedlings could be established in outplantings as performance trials, thinned at a later date, and progeny tested. Selection and crossing in subsequent progeny tests should be productive.

Black Spruce *(Picea mariana)*

Black spruce is the superior pulping species. It occupies over 2 million acres, more than half of which are poor to medium sites. These sites offer little opportunity for conversion to other species. Black spruce has been planted and seeded throughout the Region and is in demand for sites susceptible to late spring frosts, in addition to the more moist sites not well adapted to white spruce. Because of the amount of acreage now in poor sites of aspen-birch and maple-beech-birch, black spruce could be an asset within the Region. More research is needed, however, to determine its genetic potential.

Any improvement program for black spruce should parallel that for white spruce. A mass selection program, using seed from the Lake States area, should be considered. Selection of superseedlings in the nursery followed by the establishment of seedling seed orchards to serve as progeny tests similar to the white spruce program would probably be the most efficient improvement approach.

Shortleaf Pine *(Pinus echinata)*

Considering the vast acreage of poor-quality oak-hickory sites in Missouri alone, alternate species need to be found that will make better use of these sites. Shortleaf pine has possibilities and is, in fact, being used in conversion plantings. There is sufficient research to start improvement

programs with a view to conversion of poorer sites of oak-hickory in Missouri, Illinois, and Indiana. Seed-source tests to determine the possibility of extending the species range northward are suggested.

Shortleaf pine improvement programs should start with the selection of superior phenotypes, with major emphasis placed on volume yield. Of secondary importance is the improvement of stem form. Selection for resistance to Eastern gall rust appears impractical and is not of great economic importance. Clonal seed orchards should be established. Concurrent with the development of these orchards, half-sib progeny tests can be established using open-pollinated seed from the sellected ortets. Family means from these progeny tests can then be used to develop a crossing scheme to evaluate the combining ability of the clonal lines in the orchard for the mass production of F_1 seed. One or more of the F_1 progeny test areas can be rogued and used as seedling seed orchards for the production of F_2 seed.

Jack Pine *(Pinus banksiana)*

Jack pine is an important pulp species, although currently much more red pine than jack pine is being planted in the Lake States. There is great genetic diversity within the species. This, coupled with early flowering, makes jack pine a good candidate for intensive tree-improvement programs. Accurate soil-site information may indicate much more acreage on which jack pine would be better suited. As the economic pressures on pulp and paper companies lead to shorter rotations and intensive management on fewer acres, jack pine probably will become more important because of its rapid juvenile growth. Small seed source studies should be conducted to determine the feasibility of converting some of the oak-hickory sites south of its natural range to jack pine.

Jack pine lends itself readily to the seedling seed-orchard approach. Its great variability makes selection for positive phenotypes easy. Because it flowers early and abundantly there is little advantage to a clonal approach for this species. Phenotypic selection should be carried out in young natural stands and plantations. Major emphasis in selection should be given to volume yield, stem form, and apparent disease and insect resistance, in that order. Half-sib progeny test seedling seed orchards should be established. Rogued at an early age, these will start producing F_2 seed for testing on a wide variety of sites. Progeny testing should include some of the oak-hickory sites in the southern parts of the Region. Recurrent selections should be productive after the F_2 generation.

A separate selection program may be aimed at resistance to the sawfly and budworm. Since resistance to insects is usually low, these selections should be cloned, crossed, and evaluated for specific combining ability. At some later time, outcrosses to high yield and form selections can be made.

Red Pine *(Pinus resinosa)*

More red pine has been planted in the Lake States than any other species. This will probably continue to be the case in the future. Red pine is genetically relatively uniform. Although improvement is possible, the per unit gains are not expected to be as great as with other species. Added to this is the fact that available sources of seed now produce good-quality, uniform stock. In view of the projected need for this species, three separate development programs, one for each of the Lake States, are underway. Eventually they will serve to supply the seed for plantings in the area. This effort should be sufficient to meet the projected demands for the species.

White Pine *(Pinus strobus)*

Research programs now underway will do much to determine the course of future work with white pine. The results of provenance tests in the Lake States will show the best geographic sources to use in the Region. The blister rust resistance breeding project will produce some resistant types, but additional basic research is needed in relation to blister rust. Further developmental work with white pine in the Lake States depends upon an acceptable solution to the weevil problem, in spite of the fact that there is much land that could now probably be best utilized by white pine. Small seed source studies have been inaugurated to determine the possibilities of extending the range of white pine into the southern part of the Region for purposes of converting some of the oak-hickory type (Funk 1965).

Suggestions for a white pine improvement program center about its two main problems, blister rust and the weevil. Approaches to the rust resistance problem have been well documented by Heimburger (1962). Callaham (1966) gives a rather complete summary of the alternatives available to the tree breeder involved in practical programs for developing pest resistance.

Scotch Pine *(Pinus sylvestris)*

Tree-improvement programs for Scotch pine are active in European countries where the species is native. It is also receiving much attention for Christmas tree production and environmental forestry in the United States. However, considering projected demands for timber products and the alternatives available for meeting them through the use of native species, Scotch pine tree improvement programs for timber production in the Region should probably have low priority.

Aspen, Cottonwood, and Poplar *(Populus* spp.*)*

There are eight million acres of highly productive aspen sites in the Lakes States, and 10 million acres of elm-ash-cottonwood sites throughout the Region. The projected yearly increase for pulpwood consumption is seven times that of hardwood veneer. The pulp industry has learned to use the *Populus* species and some prefer it to other species. Alternatives to satisfy the demand are not very realistic when the quantity of material is considered. Although more research work needs to be done to adequately back a developmental program for *Populus*, there is already sufficient knowledge to get one started. Much genetic variation exists within the genus and significant potential for genetic improvement is apparent. The genus has rapid juvenile growth so necessary to the pulp industry of the future. Graham *et al.* (1963) reported aspen in southern Michigan growing to 80 feet in 30 years, yielding a merchantable volume of 3,450 cubic feet per acre.

Tree-improvement programs in *Populus* species will probably develop along clonal lines. Superior phenotypes in wild stands should be selected for growth rate, form, disease resistance, specific gravity, and rootability. Both male and female selections must be considered. These selections should be cloned, probably by rooting cuttings; and a clonal bank should be established. This approach will provide selected planting stock or cuttings with greater growth potential than coppice forests. One caution in establishing forests from cuttings: Do not rely on one or two clonal lines. Establish plantings using "multiclonal" lines to avoid disaster by hypersusceptibility of some clonal lines to disease pathogens. Forests established with planting stock from clonal seed orchards are not subject to the same limitations.

Because *Populus* species flower and mature seed within a short span of time, controlled pollination on cut branches under greenhouse conditions is a reasonable approach to genetic improvement. Each cross will yield large numbers of seeds for testing, a distinct advantage not possible with most other species. Crosses yielding outstanding offspring can be repeated and multiplied rapidly in clonal seed orchards.

Another approach to *Populus* improvement is concerned with polyploidy, particularly the triploid aspens that have greater growth rates than their diploid parents. Naturally occurring autotriploids have been located in the Lake States and are now under study. Some of the superior phenotypes selected for cloning may possibly be triploids.

● Table 2 summarizes tree improvement possibilities for the high priority species for tree improvement in the North Central Region. ●

Improvement of Other Species

This discussion of specific species and recommended breeding plans should not obscure the fact that to fill small but specific planting requirements for any species the established practices of tree improvement should be used. These practices include:

1. Choosing seed from proven geographic sources or sources most likely to produce the stock best adapted to the planting area.
2. Gathering seed from the best available phenotypes of the species. If planting programs of a species are to continue for some time, it may be economically feasible to establish small seed-production areas or clonal seed orchards using the untested seed that will result.
3. Screening nursery beds for the most vigorous individuals. As a minimum practice, the least vigorous individuals should be culled.
4. Silvicultural systems using "natural" regeneration methods should encourage selecting the best available phenotypes of the desired species as seed sources.

A number of other native genera and/or species show much promise for meeting the increasing demands on the forests. They have not been considered in this analysis because of a lack of basic genetics information about them. Some of these species are: *Betula papyrifera*, paper birch; *Platanus occidentalis*, sycamore; *Alnus glutinosa*, European alder; *Luriodendron tulipifera*, yellow poplar; *Fraxinus* spp., ashes; *Acer rubrum*, red maple; and *Acer saccharinum*, silver maple.

Table 2.—*Tree improvement needs, possibilities and alternatives for the high priority species for tree improvement in the North-Central Region*

Species	End use(s)	Major improvement objectives	Alternate or supplemental means of meeting projected demands:	Available sites for planting	Suggested tree improvement program	Other applied forestry research needed
Betula alleghaniensis	Veneer, hardwood paneling, furniture, cabinets, flooring	1. Yield 2. Stem form (apical dominance)	1. Timber stand improvement 2. Use substitute species on poorer sites	Some of the 3 million acres of excellent and good maple-beech-birch types	1. Phenotypic selection of superior trees 2. Establish progeny test-seedling seed orchards	1. Planting techniques 2. Seed orchard management techniques, seed harvest
Juglans nigra	Veneer, hardwood paneling, furniture, gunstocks	1. Stem straightness (apical dominance) 2. Frost hardiness 3. Anthracnose resistance 4. Yield	1. Intensive timber stand improvement practices 2. Establish more acreage of black walnut plantations	Prairie soils and agricultural land not now considered commercial forest land. Some of the 4 million acres of elm-ash-cottonwood sites.	1. Phenotypic selection of superior trees 2. Establish progeny test-seedling seed orchards	1. Even-aged management studies 2. Soils and site relationships 3. Effect of thinning and fertilizing
Larix spp.	Pulpwood, lumber, poles, pilings	1. Yield 2. Larch sawfly resistance	1. Increase supply of pine, aspen, spruce, other pulp species 2. Intensive timber improvement practices in existing stands of tamarack	Full site potential yet to be determined	1. Select superior phenotypes of Larix laricina 2. Establish clonal seed orchards followed by progeny tests 3. Provenance tests to extend range to southern part of Region	1. Site adaptability of Larix hybrids 2. Management of Larix hybrids
Picea glauca	Pulpwood, lumber, veneer	1. Yield 2. Late spring frost resistance 3. Early growth rate	1. Plant more acreage 2. Timber stand improvement in existing stands	1. Some medium and poor aspen sites 2. Some medium and poor maple-beech-birch sites 3. Replacement on excellent white spruce sites	1. Phenotypic selection of individual trees 2. Establish clonal orchards 3. Progeny tests 4. Super seedlings	1. Site adaptability of P. glauca hybrids 2. Response to intensive culture short rotation systems 3. Species comparison on various sites
Picea mariana	Pulpwood	1. Yield	1. Timber stand improvement 2. Improvement of poor sites by drainage	1. Excellent and good black spruce sites 2. Some of the poorer, low moist aspen and maple-beech-birch sites	1. Phenotypic selection of individual trees 2. Establish clonal seed orchards 3. Progeny tests -or- 4. Mass selection 5. Super seedlings used to establish seedling orchards as progeny tests	1. Response to intensive culture, short rotation systems 2. Soil-site relationship studies 3. Planting techniques on wet sites
Pinus echinata	Pulpwood lumber	1. Yield 2. Stem form	1. Intensive timber stand improvement 2. Substitute other species which might better occupy oak-hickory sites 3. Increase acreage in pine type	1. Some of the 14 million acres of oak-hickory and oak-pine sites in Missouri, Illinois and Indiana	1. Phenotypic selection of individual trees 2. Establishment of clonal seed orchards	1. Soil-site relationships 2. Graft incompatibilities 3. Economics and techniques of conversion in oak-hickory types
Pinus banksiana	Pulpwood lumber, poles	1. Yield 2. Stem form 3. Budworm resistance 4. Nonserotinous cones	1. Substitute other pine species 2. Increase planting 3. Timber stand improvement on better sites	1. Present jack pine sites 2. Some of the poorest aspen and birch-beech-maple sites 3. Some poorer sites of the red and white pine types	1. Phenotypic selection for yield 2. Establish progeny test-seedling seed orchards and/or 3. Select for resistance 4. Establish clonal orchard 5. Progeny test 6. Outcross	1. Soils-site relationship studies 2. Techniques for evaluating insect resistance

Table 2 continued.

Species	End use(s)	Major improvement objectives	Alternate or supplemental means of meeting projected demands	Available sites for planting	Suggested tree improvement program	Other applied forestry research needed
Pinus banksiana	Pulp, lumber, poles	1. Yield 2. Stem form 3. Budworm resistance 4. Nonserotinous cones	1. Substitute other pine species 2. Increase planting 3. Timber stand improvement on better sites	1. Present jack pine sites 2. Some of the poorest aspen and birch-beech-maple sites 3. Some poorer sites of the red and white pine types	1. Phenotypic selection for yield 2. Establish progeny test-seedling seed orchards and/or 3. Select for resistance 4. Establish clonal orchard 5. Progeny test 6. Outcross	1. Soils-site relationship studies 2. Techniques for evaluating insect resistance
Pinus resinosa	Lumber, veneer, pulp, poles	1. Yield 2. Shorter rotations	1. Timber stand improvement on better sites 2. Substitute other species on poorer sites	1. Some of the 7 million acres of poorer aspen-birch sites 2. Some of the 6 million acres of poor maple-beech-birch sites 3. Some of the 300 thousand acres of poorer white pine sites	1. One parent-progeny from 1200 Wis. selections: test in 4 zones. Leave top 25% best families in a seed orchard. 2. Establish clonal seed orchard from selection of 5 best trees from 17 best families for Minn. 3. One-parent progeny from 290 Mich. selections tested in a 15-replicate design	1. Practical methods of stand conversion 2. Direct seeding techniques
Pinus strobus	Lumber veneer, poles	1. Yield 2. Blister rust resistance 3. Weevil resistance	1. Timber stand improvement 2. Substitute red pine 3. Develop alternative methods of blister rust control 4. Develop biological, silvicultural or chemical control of weevil 5. Plant only in rust hazard areas	1. Some of the medium site index aspen and about 4 million acres of poor maple-beech-birch sites 2. Possible use in Illinois, Iowa, Indiana and Missouri for conversion of medium and poor oak-hickory sites	1. Provenance test: oak-hickory sites in Central States 2. Make 700 resistant selections. Make controlled crosses with resistant pollen. Inoculate progeny in nursery. Establish survivors in clonal seed orchard	1. Control of white pine weevil through management or genetics
Populus spp.	Pulp, veneer	1. Yield 2. Shorter rotations 3. Disease resistance 4. Fiber length 5. Specific gravity	1. Substitute other pulp species 2. Intensify culture of existing types	1. 8 million acres of good and excellent aspen-birch sites 2. Some of 4 million acres of elm-ash cottonwood sites	1. Select superior clones from natural stands and plantations for growth rate, form, disease resistance. Male and female clones must be considered. Propagate by root cuttings 2. Establish rooted cuttings in clonal bank 3. Progeny test (controlled and open) all female clones 4. Establish in clonal bank all superior material resulting from seed orchard	1. Clonal silviculture 2. Planting techniques 3. Vegetative propagation techniques 4. Harvest methods 5. Management of clonal orchards for the production of hybrid seed 6. Seed collection, extraction storage 7. Intensive short rotation culture

Program Organization and Execution

Most forest land in the North Central Region is privately owned (see table 3 in Appendix). Although there is wide variation in the forest management practiced on private forest land, much of this land is not managed at all. If the projected demands for forest products are to be met, it is essential that the intensity of management on these lands be increased.

A number of research studies are needed before intensive management of privately owned forest land can be successfully launched.

Private land ownershhip, in too many cases, involves antipathy toward commercial production of timber, a lack of awareness of its compatibility with other uses, and little or no favorable motivation. On the other hand, many obvious and unfavorable social pressures affect the landowner's decisions. A thorough study of the many factors that contribute to this attitude might provide a plan for corrective action. Such a plan, for instance, might suggest the need for commercial organizations that would provide *full* forest land management services at reasonable cost to small, especially absentee, landowners.[7]

Reforestation, underplanting, and converting to more desirable or productive species are intensive silvicultural management practices. Not only motivation, but facilities necessary to carry out these practices need to be organized to take full advantage of the potential of private woodlands.

Additional nurseries to supply planting stock to the thousands of small acreages would not be needed. State, Soil Conservation District, and private nurseries could rapidly expand their production if the demand increased. Needed, however, are programs to develop and supply genetically improved seed for planting stock throughout the areas served by the nurseries.

Because of the high proportion of forest land in the Region being serviced by the State nurseries, a high priority job is the acceleration of intensive tree-improvement programs by the Departments of Natural Resources of the States of the Region, particularly the Lake States.

Although privately owned, the land of the pulp and paper, veneer, and lumber companies presents a somewhat different problem. Acreages are much larger than the average for other "miscellaneous owners." The industries owning the land have explicit management objectives; the land is frequently managed on a multiple-use basis, but in such a manner as to best provide for their own needs. Motivation is not a serious consideration in dealing with the management of industrial forests. Indeed, some of the largest industrial interests in the Region have been leaders in the forest management field. Taxation, harvesting, and transportation costs, and plenty of available wood have been the major deterrents to intensive forest management.

Tree-improvement has not been of as much concern to the pulp and paper industry in the Region as it has in the South because a surplus of pulp species has been available in the North.

However, as raw material costs increase, pulp and paper companies may find intensive, short-rotation, single-purpose management systems, using trees bred for this specific purpose and located near their mills, to be attractive. Research is needed to determine the feasibility of such systems.

The initial breeding programs, for companies using the same species, could be operated on a cooperative basis. Trees bred to furnish maximum yields of fiber on one company's land would have the same potential on the adjacent land of another. There would be a distinct advantage to selecting the best individuals from the larger combined acreages of several companies. It may not be judicious to hire a professional tree breeder for the benefit of one company, but it may definitely be productive to do so for a large program supported by several companies.

There is precedent for this type of program. The North Carolina State - Industry Cooperative has been active since 1956. Its membership is composed of 18 industries and the Forestry Division of the States of North Carolina and Virginia (North Carolina State University 1967). Similarly, in the northeast, 16 pulp and paper companies and State and Private Forestry Division of the Forest Service have joined in an informal cooperative tree-improvement program for white spruce and balsam fir.

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[7] *USDA Forest Serv. Forestry in the Upper Great Lakes Region. Forest Serv. Task Force Rep. to Upper Great Lakes Reg. Comm. 1968.*

Summary

The function of this problem analysis is to interpret economic trends and relate them to planning for applied research and developmental or action programs in forest-tree improvement.

It is impossible to develop precise quantitative methods for analyzing long range forestry programs. So this analysis is qualitative, describing general trends and judgments rather than positive or discreet criteria for choosing and conducting projects. Moreover, as projection techniques become more refined, as new technology creates new demands or erases old ones, it is likely that some of the recommendations and forecasts presented here will prove to be in error. However, there will be less chance of error than if projected demands and land-use possibilities were considered only lightly or not at all.

Recommendations in the present analysis need to be reviewed periodically and updated. New information coming from more basic forestry and genetics research, innovations of manufacturing technology, shifting social trends, and more recent projections make this review process imperative.

Finally, specific recommendations are made in this publication that somewhat restrict species alternatives open to applied research, developmental, and action programs in tree improvement. These recommendations should not be interpreted as limiting the scope of the more basic forest genetics research programs. On the contrary, they point out the need for more fundamental studies on a greater number of species. The recommendations in this problem analysis are limited by the amount of basic information available *now*. When present and future research results are available, more alternatives will be available to the tree improver.

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Appendix

Table 3.—*North Central Region commercial forest land*[1] *by ownership (Thousand Acres)*

State	Total land area	Total commercial forest	Federal land				State	County and municipal	Private land						
			Nat'l forest	BLM	Indian	Misc.			Total	Comm. forest land	Pulp & paper Co's	Lumber	Other indus.	Farmer	Misc. private
										(percent)					
Illinois	35,795	3,761	188	--	--	41	11	--	3,521	94	--	17	--	2,216	1,288
Indiana	23,158	3,960	112	--	--	65	115	2	3,616	91	--	9	--	2,833	774
Iowa	35,861	2,595	3	--	1	9	22	2	2,558	95	--	--	--	2,282	276
Michigan	36,492	19,121	2,420	9	21	90	3,695	85	12,791	67	946	485	117	3,841	7,412
Minnesota	51,206	17,056	2,141	64	516	92	3,304	3,416	7,522	44	630	48	37	3,344	3,464
Missouri	44,248	14,977	1,310	--	--	51	199	25	13,391	90	--	279	--	9,228	3,885
Wisconsin	35,011	15,396	1,372	5	423	110	541	2,615	10,799	70	713	220	--	6,372	3,025
TOTAL	261,771	76,866	7,546	78	961	458	7,887	6,145	54,198	--	2,289	1,058	154	30,116	20,124
Percent of commercial forest land		100	9.8	.1	1.3	.6	10.3	8.0	70.5	--	3.0	1.4	.2	39.1	26.2

1/ Source: USDA Forest Service (1965).

Table 4.—*Timber types; North Central Region, by site class*
(Thousand Acres)

Timber type	ILLINOIS[1] Total	Ex.	Good	Med.	Poor	INDIANA[2] Total	Ex.	Good	Med.	Poor	IOWA[3] Total	Ex.	Good	Med.	Poor
Hardwood types															
Oak-hickory	2,232	34	435	1,196	567	2,389	251	448	1,552	138	1,036		156	520	360
Aspen-birch	9			9		13	4	6	3		20		3	10	7
Elm-ash-cottonwood	1,442	380	505	517	39	554	105	148	297	4	1,219		183	610	426
Maple-beech-birch	14			14		788	92	142	529	25	78		12	39	27
Oak-pine	12				12	46		3	26	17					
Oak-gum-cypress	17			17		52	9	6	32	5					
Total hardwood types	3,726	414	940	1,753	618	3,762	461	753	2,439	189	2,353		354	1,179	820
Conifer types															
White pine	1			1											
Loblolly shortleaf	35			17	18	54	12	3	32	5					
Total conifer types	36			18	18	54	12	3	32	5					
Misc.; nonstocked, brush etc.	1										242				
Total	37			18		3,816	473	756	2,471	194	2,595				

Timber type	MICHIGAN[4] Total	Ex.	Good	Med.	Poor	MINNESOTA[5] Total	Ex.	Good	Med.	Poor	MISSOURI[6] Total	Ex.	Good	Med.	Poor
Hardwood types															
Oak hickory	2,405	586	615	672	532	1,039	65	152	372	450	11,333	85	1,240	7,495	2,513
Aspen-birch	4,675	1,626	1,426	1,209	414	6,254	740	1,865	2,162	1,487					
Elm-ash-cottonwood	1,936	495	563	518	360	1,949	116	317	508	910	2,180	248	1,031	830	71
Maple-beech-birch	5,245	654	1,354	2,230	1,007	1,009	52	167	416	374	85		37	43	5
Oak-pine											639			379	260
Oak-gum-cypress											410	43	229	128	10
Total hardwood types	14,261	3,361	3,958	4,629	2,313	10,251	973	2,501	3,458	3,221	14,647	376	2,537	8,875	2,859
Conifer types															
Spruce-fir	1,082	53	483	440	105	1,248	128	368	486	266					
Jack pine	897	5	123	729	40	885	15	158	560	152					
Black spruce	428	50	62	207	110	1,408	170	372	422	444					
Northern white-cedar	1,188	122	181	439	446	417	16	61	192	148					
Red pine	596	128	176	282	10	284	16	93	151	24					
Tamarack	176	3	33	103	37	568	23	85	182	278					
White pine	154	6	53	87	8	134		10	33	91					
Loblolly shortleaf											330		17	160	153
Total conifer types	4,521	367	1,111	2,287	756	4,944	368	1,147	2,026	1,403	330		17	160	153
Misc.; nonstocked, brush etc.						1,861									
Total	18,782					17,056					19,977				

Timber type	WISCONSIN[7] Total	Ex.	Good	Med.	Poor	REGIONAL TOTALS Total	Ex.	Good	Med.	Poor
Hardwood types										
Oak hickory	2,573	618	669	720	566	23,007	1,639	3,715	12,527	5,126
Aspen-birch	4,611	1,059	1,380	1,388	784	15,582	3,429	4,680	4,781	2,692
Elm-ash-cottonwood	941	151	215	260	315	10,221	1,495	2,962	3,640	2,125
Maple-beech-birch	2,663	234	559	1,116	754	9,882	1,032	2,271	4,387	2,192
Oak-pine						697		3	405	289
Oak-gum-cypress						479	52	235	177	15
Total hardwood types	10,788	2,062	2,823	3,484	2,419	59,868	7,647	13,866	25,917	12,439
Conifer types										
Spruce-fir	373	28	140	147	57	2,703	209	991	1,073	428
Jack pine	692	11	109	501	71	2,474	31	390	1,790	263
Black spruce	260	31	53	101	74	2,096	251	487	730	628
Northern white cedar	223	16	33	93	81	1,828	154	275	724	675
Red pine	148	20	46	74	8	1,028	164	315	507	42
Tamarack	185	6	30	84	65	929	63	148	369	349
White pine	174	3	37	70	64	462	9	100	190	163
Loblolly shortleaf						419	12	20	209	176
Total conifer types	2,055	115	448	1,070	420	11,930	893	2,726	5,592	2,724
Misc.; nonstocked, brush etc.	2,553					4,667				
Total	15,396					76,465	8,540	16,592	31,509	15,163

1/ From Essex and Gansner (1965).

2/ From unpublished data on file at North Central States Experiment Station, USDA Forest Service, St. Paul, Minn.

3/ From Thornton and Morgan (1959).

4/ Unpublished data on file at North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minn.

5/ Stone (1966).

6/ Unpublished data on file North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minn.

7/ Stone and Thorne (1961) and unpublished data on file at North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minn.

Table 5.—*Basal area growing stock all commercial forest land by States in North Central Region*
(In thousand square feet)

Species	Illinois	Indiana	Iowa	Michigan	Minnesota	Missouri	Wisconsin	Total	Percent
Balsam fir				51,206	111,071		24,231	186,508	5.162
Eastern redcedar	307		636				157	1,100	0.030
Tamarack				5,136			7,430	12,566	0.348
Norway spruce					44,538			44,538	1.232
White spruce				14,703	14,305		** 5,618	34,626	0.957
Black spruce				17,491	129,149		6,594	153,234	4.241
Red pine				18,320	26,336		5,785	50,441	1.395
White pine				18,771	15,068		14,819	48,658	1.346
Jack pine				29,531	88,277		25,286	143,094	3.960
Shortleaf pine	1,483	831				19,106		21,420	0.592
Baldcypress	217	222						439	0.011
Northern white-cedar				77,360	42,443		26,996	146,799	4.062
Eastern hemlock				33,404			15,818	49,222	1.361
Other softwoods	114	2,728		372		* 2,430		5,644	0.155
Hard maple	5,474	14,621	998	125,929	19,541	3,101	55,675	225,339	6.236
Soft maple	12,803	5,899	6,313	75,618	14,341	2,937	37,022	154,933	4.287
Select white oak	30,926	26,341	9,738	27,972	27,950	74,876	40,081	237,884	6.584
Select red oak	9,401	12,095	6,759	40,944	39,709	13,924	64,345	187,177	5.180
Other white oak	7,585	6,277	9,269			57,600		80,731	2.234
Other red oak	27,382	20,192	5,250	23,933		96,740	31,895	205,392	5.684
Select hickory	14,768	22,856	6,875	4,899		29,201	7,051	85,650	2.370
Other hickory	8,146							8,146	0.224
Yellow birch				29,793	2,642		15,101	47,536	1.315
Paper birch				39,008	113,974		44,292	197,274	5.460
Beech	645	5,922		21,438			2,303	30,308	0.838
Black walnut	4,351	4,205	3,795	145		8,443	569	21,508	0.594
Ash	13,536	10,476	2,371	29,518	51,081	6,340	30,819	144,141	3.990
Elm	22,687	5,604	21,144	41,613	41,533		38,590	171,171	4.737
Sweetgum	3,158	2,433				1,611		7,202	0.198
Tupelo gum	732	1,635				1,256		3,623	0.100
Cottonwood	5,554	2,802	5,070	2,969	773			17,168	0.474
Aspen (bigtooth and quaking)	676	1,202	1,128	129,769	316,638		161,007	610,420	16.890

* Mostly redcedar and cypress.
** 46 percent white spruce; 54 percent black spruce reported only as spruce.

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